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MOTOR BOATS

A THOROUGHLY SCIENTIFIC DISCUSSION OF THEIR DESIGN, CONSTRUCTION AND OPERATION,

BY

PROFESSOR W. F. DURAND,

Author of *Practical Marine Engineering, Resistance and Propulsion of Ships, etc.*,

with additional chapters on The Uses of Kerosene and Alcohol in Internal Combustion Engines.

NEARLY 100 ILLUSTRATIONS.

INTERNATIONAL MARINE ENGINEERING,

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PREFACE.

The great interest manifested in the subject of Motor Boats, which began in 1904, led the publishers of INTERNATIONAL MARINE ENGINEERING to arrange with Professor W. F. Durand to write a series of articles covering the subject exhaustively and from a thoroughly scientific point of view.

Each month, as the serial progressed, more and more attention was attracted to it, and, as all back numbers of the magazine have sold out, it has become necessary to republish the articles in book form. Such is their quality that no explanation or apology is necessary for putting another book on the market.

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MOTOR BOATS.

THE PROBLEM OF THE BOAT.

Ten years ago the motor boat, or boat using some form of internal combustion engine for power, was a comparative curiosity. To-day they are commonplace on almost every harbor, lake, and water course throughout the country, from the Atlantic to the Pacific and the Great Lakes to the Gulf, while in Europe and elsewhere over the civilized world their increase in utility and popularity has been no less marked. As a line of industry collateral with the automobile and gas engine power industries, it has shared in the wonderful growth which these latter have enjoyed, and has furnished opportunity for labor and capital in amounts to suit the capacity of many moderate and small investors in lines of industrial work. A motor-boat plant is not necessarily large or expensive, nor need it absorb any very large capital. It has thus stood as one of the relatively smaller lines of industry into which many might venture with capital which would be entirely without significance in the larger lines of industrial work, and has thus played a beneficent part in aiding the moderate or small industrialist to find outlet for his capital, energy, and skill, while the product has steadily worked its way into the confidence and favor of the public until motor boats of one type or another are found literally by thousands in all parts of the country, and adapted to almost every demand of either commerce or pleasure.

In approaching a discussion of the motor-boat problem it will be well to obtain a clear idea of what may be called in its broadest terms the "Problem of the Boat." This contains the following main items:

(*a*) To design and build a floating structure which, with a certain weight of material, shall with safety be capable of carrying a certain load and admit of propulsion through the water at a certain speed.

(*b*) To design and build a motive power plant which shall serve to liberate, transform, and adapt some store of natural energy into a form available for propulsive purposes.

(*c*) To apply to the purposes of propulsion the power thus transformed, and so to realize the ultimate purpose of the combination of hull, motor, and propeller.

The important points under (*a*) are as follows:

(1) Weight of hull.

(2) Weight of additional load which may be carried.

(3) Resistance to propulsion.

(4) Safety.

(5) Cost of construction and of maintenance.

The fundamental purpose which must be held in view by the designer and builder must be to combine in the highest degree the least weight of structure with maximum capacity for additional load and least resistance to propulsion, all with due regard to safety and to the fundamental factor of all engineering work—the cost of construction and of maintenance.

The important points under (*b*) are as follows:

(1) Weight and space required for motive-power plant.

(2) Efficiency as a means of transforming energy into motive power.

(3) Simplicity, reliability, and general adaptation to the conditions and requirements of the case in hand.

(4) First cost.

(5) Cost of operation and maintenance.

The fundamental purpose here must therefore be to combine in the highest degree the utmost of efficiency as a means of transforming energy into power available for propulsion, the least weight and space required, and the utmost of simplicity, reliability, and adaptation, and all with minimum first cost and costs of operation and maintenance.

The important points under (*c*) are as follows:

(1) Efficiency as a means of utilizing for propulsion the power furnished by the power plant.

(2) Adaptation to the control of the boat, and to any special conditions or requirements which may exist.

(3) Simplicity and reliability.

The fundamental purpose here must therefore be to combine most perfectly the highest efficiency of the propulsive agent as a means of utilizing power for propulsion, with the utmost simplicity, reliability, and adaptation to the ready and sure control of the boat and to any other special conditions or requirements.

A review of these various requirements will show that the efforts toward general advancement must take the following directions:

(1) Decreased weight of hull.

(2) Increased internal space and carrying capacity.

(3) Decreased resistance.

(4) Decreased weight and space required for motive-power plant for a given power, or increased power for a given weight or space.

(5) Increased efficiency of motive-power plant as a means of transforming natural energy into motive power.

(6) Increased efficiency of propulsion.

(7) All with due regard to safety, simplicity, reliability, and the various items of cost.

It will be clear that these various requirements are mutually inconsistent in various degrees, and that no boat can contain all desirable features in the highest degree. In the general design of a boat in any given case it is therefore necessary to give to each of the various requirements and conditions a just relative weight, and then to seek for the best combination of features, having in view the especial purpose for which the boat is intended. Thus in some cases everything must be sacrificed for speed, while in others moderate speed, comfort, and safety are desired; while in others, again, economy of operation with large carrying capacity must be provided; and thus the design as a whole will take shape as the various features are combined in such manner as may best answer the special demands of the case.

It will best answer the purpose of these articles to approach the more detailed consideration of the problem through section (*b*) above, the motive-power plant, its character, design, and installation.

Remembering the fundamental requirement it is clear that the process of power development and application may be worked out in a variety of ways. In the general case the entire process may be divided into three steps or considered under three heads:

(1) The storage of energy.

(2) The liberation or manifestation of energy.

(3) The transformation of energy from the form under which it is first liberated, into mechanical work available for propulsion. In the familiar steam motive-power plant the coal or oil fuel represents the storage of energy, the boiler provides for its liberation as heat, and the engine and propeller for its transformation and utilization as propulsive work. This is the form of motive-power plant which stands preëminent with reference to the world's work of marine transportation, and it is only in small corners of the broad field, such as that with which we are to be concerned in the present series of articles, that any other form of motive power has gained acceptance.

In the naphtha launch, which represents one of the earliest forms of special motive-power boats, the energy is stored in the naphtha or other form of fuel, while it is transformed by combustion into heat, and then embodied in the naphtha vapor from whence it is transformed by the engine and propeller into the mechanical work of propulsion.

In the alco-vapor launch likewise, the energy is stored in the kerosene, gasoline, or other form of fuel, thence transformed into heat, and embodied in the alcohol vapor, and then by the engine and propeller transformed into the work of propulsion.

In the electric launch, on the other hand, the energy is stored in the cells of a storage battery, whence it is transformed into mechanical work by the motor and into work of propulsion by the propeller.

In the typical modern motor boat using the gasoline combustion engine, the energy is stored in the gasoline, this is transformed into gas and mixed with air in the carbureter, while the energy is liberated as heat in the engine cylinder, and then directly transformed into mechanical work by the engine, and into propulsive work by the propeller.

In the special type known as the suction-gas engine, using coal as primary fuel, the energy is stored first in the coal and then in the gas formed in the producer. The energy is then liberated as heat in the engine cylinder, and transformed as in other types, ultimately into the work of propulsion.

These brief references to the various forms of solution for the general motive-power problem are introduced at this point simply to show the diversity of special solution which is not only possible but practicable for certain limited requirements, and to impress the relation of each to the other, and the fact that all are but special means of fulfilling certain fundamental conditions common to all problems dealing with the development and utilization of natural energy for power purposes.

THE GAS ENGINE.—PRINCIPLES OF OPERATION.

We must now turn to a more detailed examination of the gas engine and the solution which this furnishes for the general motive-power problem of boat propulsion. In the typical gas engine the main problem is as follows:

Given a hydrocarbon or other form of gas, required its combustion and the transformation into mechanical work of the heat energy thus developed.

The first step is combustion or union with oxygen. But the gas itself will not burn, and must therefore first be mixed with a suitable amount of oxygen. This is accomplished most cheaply by using air and accepting the nitrogen present simply as a diluting ingredient of the mixture. Again, it is found that such gases,

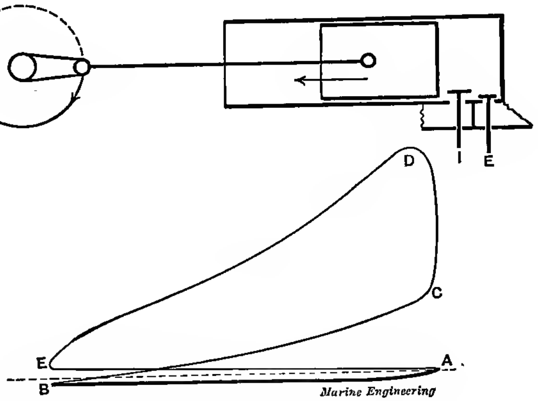

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FIG. I.—FOUR-CYCLE ENGINE, INTAKE STROKE.

even when mixed with a suitable amount of air, will not burn readily at ordinary pressures, and it is not until they are compressed to a high degree that the combustion once started will propagate itself with sufficient vigor and rapidity to render the operation practicable and useful as a factor in the cycle of a gas engine.

With this by way of introduction we may proceed with the description of the operation of the typical or four-cycle gas engine. This type of engine receives its name from the fact that the entire cycle of operations is distributed over four strokes of the piston as follows:

(1) Intake of charge of mixed gas and air.
(2) Compression.
(3) Combustion and expansion.
(4) Exhaust.

In Fig. 1 the piston is just beginning the intake stroke, the intake valve *I* is open, and the exhaust valve is closed. The piston moves as indicated by the arrow, and at the end of the stroke the cylinder is filled with the charge. This operation is accomplished at a practically constant pressure, slightly below atmospheric pressure, and the line indicating this relation between pressure and volume is shown at *AB*, the intake line of the indicator card *ABCDE*. During the next stroke, shown in Fig. 2, the intake valve is closed and the piston returns on its path thus compressing the gas in accordance with the law of rising pressure shown by the line *BC* of the indicator card. At the close of this stroke the gas is under pressure as denoted by the point *C* and then ready for firing. The ignition being effected by the electric spark, the com-

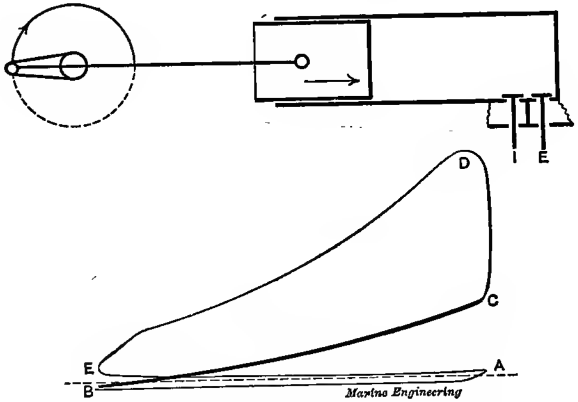

FIG. 2.—FOUR-CYCLE ENGINE, COMPRESSION STROKE.

bustion is rapidly propagated throughout the charge, heat energy is liberated, and the pressure rises as shown by the line *CD.*

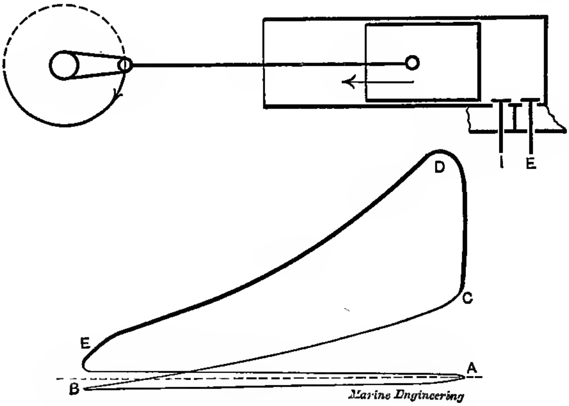

FIG. 3.—FOUR-CYCLE ENGINE, POWER STROKE.

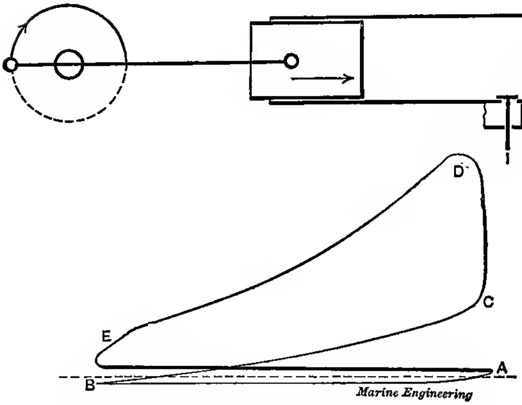

FIG. 4.—FOUR-CYCLE ENGINE, EXHAUST STROKE.

At the same time the piston begins its third stroke as shown in Fig. 3, urged by the pressure of the expanding gas, the pressure decreasing as the volume increases as shown by the expansion line *DE*. The entire line *CDE* of the diagram corresponds, therefore, to the operations of combustion and expansion, and gives the history of the relation between volume and pressure for the third stroke of the cycle. During the next stroke the piston returns to its original position as shown by Fig. 4, and the waste gases are rejected through the open exhaust valve. The corresponding line on the indicator diagram is shown by *EA*, thus completing the diagram and the cycle. The following stroke a new cycle begins and the same operations are repeated.

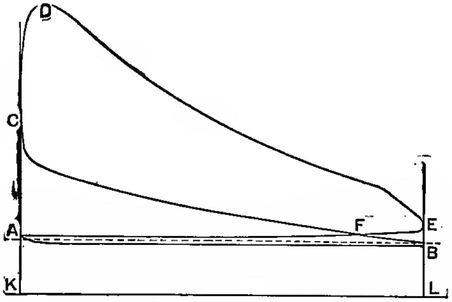

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FIG. 5.—INDICATOR CARD, FOUR-CYCLE ENGINE.

Referring again to these figures indicating the operation of the engine throughout one complete cycle, it will be clear that the gases act on one side of the piston only, the other side being exposed to the constant pressure of the air. Engines operating in this manner are known as "single acting." It is furthermore clear, since the air always acts by pressure inward, that it will oppose the out stroke and aid the in stroke by equal amounts, and that in consequence the pressure of the air exercises no resultant influence on the net work done by the engine. The net work will therefore be correctly given by considering simply the work done by the gas alone. From this point of view it is seen that during stroke No. 1 the gas comes in with pressure as shown by the line *AB,* Fig. 5, slightly below the atmospheric line; but reckoning from the zero of pressure, positive work is done on the piston represented by the area *ABLK.* During the second stroke the gas is compressed and takes work from the engine represented by the area *CBLK.* During the third stroke the gas gives work to the engine represented by the area *KCDEL,* while during the fourth stroke the piston must push the gas out, thereby doing work on it represented by the area *EAKL.* A little thought will show that as the result of these four strokes work is done *by* the gas on Nos. 1 and 3, and *on* the gas on Nos. 2 and 4; and further, that the net work of the cycle will be given by the difference between the two loops of the diagram *CDEF—ABF.*

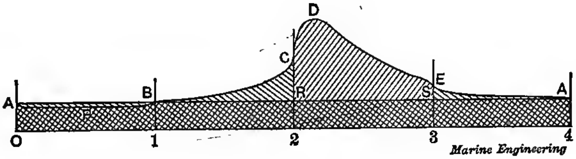

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FIG. 6.—DISTRIBUTION OF WORK IN FOUR-CYCLE ENGINE.

While it is evident that the air always pressing in the one direction will not affect the total work of the cycle, it will, nevertheless, affect the net work for each stroke individually, and hence the distribution of net work through the cycle. This is a point of some importance and may be seen more clearly by the aid of Fig. 6.

In this diagram the four lines of Fig. 5 are run out consecutively, the letters being the same in both figures. The four strokes are therefore from 0 to *1*, *1* to *2*, *2* to *3*, and *3* to *4*. The straight line *AA* represents atmospheric pressure and *04* the zero of pressure. Then during the first stroke the work done by the gas and against the air is represented by the area *0APB1,* while the work done on the air is represented by the rectangle *0AB1,* The net work for this stroke is therefore done *on* the air, and is shown by the area *APB*. Similarly during the second stroke the work done on the gas is shown by *1BC2*, and that done by the air is shown by *BR21*. The net work is therefore done *on* the gas, and is shown by the area *BCR*. During the third stroke the work done by the gas is shown by *2CDE3*, and that done on the air by *RS32*. The net work is therefore done *by* the gas and is shown by the area *RCDES*. During the fourth stroke the work done on the gas is shown by *3EA4*, and that done by the air is shown by *3SA4*. The net work is therefore done *on* the gas, and is shown by the area *SEA*. To aid in understanding these various relations, the work done *by* the air or *by* the gas is shown by hatching with lines inclined downward to the left, while work done *on* the air or *on* the gas is shown by hatching with lines inclined downward to the right. The net work for each stroke shows then as a singly hatched area, and the direction of the lines shows whether it is done *by* or *on* the engine. Thus it is clear that for the first, second, and fourth strokes the net work is done *by* the engine either *on* the gas or *on* the air, while for the third stroke the net work is done *on* the engine and *by* the gas. The entire net work for the cycle will therefore be represented by the difference between the area *RCDES* and the sum of the three areas, *APB, BCR, SEA*. A little thought will show that this difference will have the same value as the net result derived from the indicator card of Fig. 5, and as referred to above. It is furthermore evident that the net work of stroke number 3, represented by the area *RCDES*, must be sufficient to provide for the external work (of propulsion, for example) plus the work of internal friction, both for the entire cycle, plus the work represented by the three other smaller areas for the three other strokes of the cycle. It is also clear that the inertia of the moving parts must be depended on to maintain the motion during strokes *1*, *2*, and *4*, for which net work is absorbed rather than given out. This shows in particular the need of a heavy flywheel with a single four-cycle engine giving but one power impulse in four strokes. The application of these principles to multiple cylinder engines will be referred to at a later point. In the meantime it may be noted that the distribution of work through the cycle, as shown

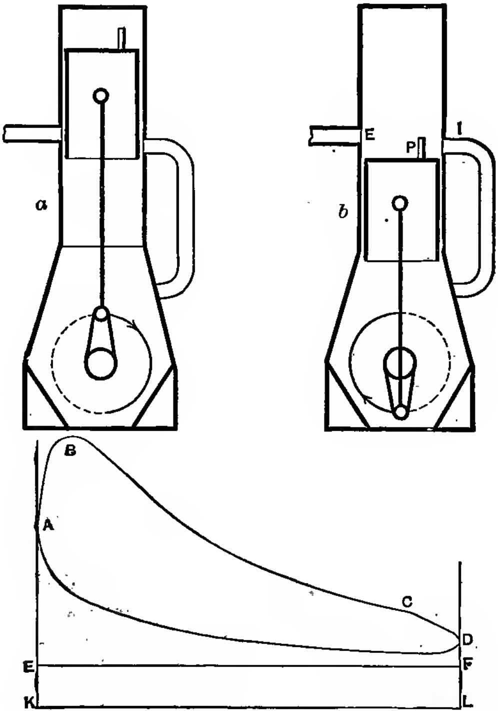

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FIG. 7.—TWO-CYCLE ENGINE, WITH INDICATOR CARD.

by these diagrams, has an important bearing on the operation and adaptation of the engine for various purposes, and the interested reader is urged to obtain a thorough grasp of these various diagrams and of the facts which they represent.

Two-Cycle Engine: By a somewhat different mechanical arrangement of the engine it is found possible to condense the essentials of the cycle into two strokes instead of four, and thus to obtain one power stroke every revolution of the engine instead of every two revolutions, as in the four-cycle engine.

The operation of this engine may be explained by the aid of Fig. 7. The crank case, as here shown, is inclosed gas-tight and provides in effect a closed extension to the lower end of the cylinder. In *a* the piston is at the top of the stroke. During the preceding up stroke a fresh charge has been undergoing compression above the piston and at the instant shown in the figure is ready for firing. During the same up stroke another fresh charge has been drawn into the crank case through the inlet valve. At the instant shown in *a*, then, the gas has reached its highest compression pressure as indicated by the point *A* of the diagram. The charge is then fired, the pressure rushes up to *B* and the piston is urged along the down or power stroke under the action of the expanding gas in the same manner as with the four-cycle engine. This entire operation is indicated by the line *ABC* of the indicator card. Toward the end of the stroke the piston uncovers the exhaust passage *E*, Fig. *7b*, exhaust begins, and the pressure drops as shown by the line *CD*. An instant later the piston uncovers likewise the inlet passage *I*, and the fresh gas which has been compressed in the crank case during the down stroke now finds relief by expansion into the cylinder through this passage. A deflecting plate *P* is commonly fitted on the piston, as shown, in order to deflect upward the incoming charge, and prevent its short-circuiting across direct to the exhaust passage. This deflection of the inflowing gas is also useful as a means of chasing or scavenging the spent gases out of the cylinder, and thus realizing substantially a cylinder full of fresh gas for each power stroke. These various operations are supposed to take place while the piston is moving slowly near the end of the stroke. As the piston begins to return it shuts off first the inlet and then the exhaust passage, the escape of the spent gases being then supposed to be complete. Actually, the events cannot be quite so accurately timed, and in practice either some little spent gas will still remain in the cylinder or some of the fresh charge will escape. However, with the charge in whatever condition it may be found at the closure of the exhaust passage, the piston continues its upward stroke, compressing the gas as shown by the line *DA* of the diagram, and thus preparing for the firing point at the beginning of a new cycle.

In analyzing the work of the cycle it will be clear, fixing our attention on the gas above the piston, that the work done *by* the gas on the down stroke is represented by the area *KABCDL*,

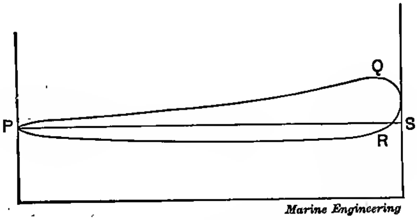

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FIG. 8.—CRANK CASE DIAGRAM.

while that done *on* the gas during the up stroke is represented by *KADL*. The net work for the space above the piston is thus shown by the area *ABCD*. But this is not all. In the two-cycle engine with its closed crank case the pressure of the gas below the piston is not the same for each stroke. An indicator attached to the crank case would in fact show a diagram similar to Fig 8. The line *PQ* shows the compression in the crank case during the down stroke, reaching a maximum value at *Q*, just before the opening of the inlet passage as above described. The pressure then equalizes with that above the piston at a value slightly above the atmosphere, and then as the piston reverses its motion and begins its up stroke the pressure falls slightly below that of the atmosphere, where it remains during the stroke as shown by *RP*. The net work done *on* the gas in the crank case is therefore shown by the area *PQR*. The actual net work of the cycle will therefore be given by the difference between these two diagrams.

In Fig. 9 is shown the analysis of the pressures above and below the piston for each stroke after the manner of Fig. 6. Work done *on* the gas is shown by hatching inclined downward to the right, and work done *by* the gas by hatching inclined downward to the left. The singly hatched area *ABC* shows then the net work done by the gas from the beginning of the stroke up to the point *C*, while the singly hatched area from *C* to the end of the cycle shows the net work done *on* the gas during the rest of the cycle. That from *C* to *D* is done on the gas below the piston and that from *D* to *EF* is done on the gas above the piston while on the compression stroke.

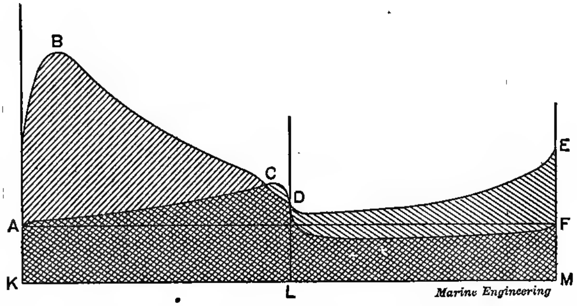

FIG 9.—DISTRIBUTION OF WORK IN TWO-CYCLE ENGINE.

Crank Effort. A further point of importance arises in connection with the turning effort on the crank and its relation to the crank angles when several engines are coupled to one shaft. Taking first the four-cycle engine and referring to Fig. 10*a*, let the strokes be numbered *1*, *2*, *3*, and *4* and indicated as shown, and let No. *3*, indicated by the heavy line, be the power stroke. Then it is easily seen that in order to obtain a power stroke and turning effort every other stroke, a second cylinder (*b*) must be provided with its cycle displaced two strokes from that of (*a*). The strokes for two cycles may then be represented as in the diagram, the numbers referring solely to (*a*). Then remembering that the heavy line represents the power stroke in each engine, it will be seen that such stroke occurs once a revolution in one cylinder or the other, and hence that with this arrangement we obtain continuously one power stroke per revolution of the shaft. It is easily seen further that the cranks of both engines must lie in the same direction and not opposite, as might at first thought have been expected. With two cranks opposite, and using the same mode of representation, it is seen that the distribution of power strokes will be indicated by the diagram of Fig. 11. This shows

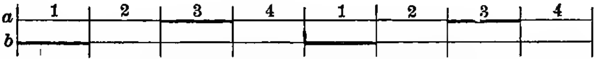

FIG. 10. DISTRIBUTION OF POWER STROKES, TWO CYLINDER FOUR CYCLE ENGINE WITH CRANKS TOGETHER.

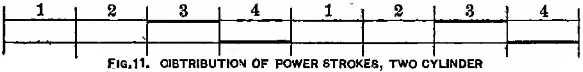

FIG. 11. DISTRIBUTION OF POWER STROKES, TWO CYLINDER FOUR CYCLE ENGINE WITH CRANKS OPPOSITE.

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power strokes or turning effort on two successive strokes, and then two strokes without power or turning effort. This is obviously a less desirable arrangement, so far as turning effort is concerned, than that with the cranks together as shown in Fig. 10. On the other hand, this same arrangement is much the more desirable so far as running balance is concerned. With the cranks together the engine by itself is entirely out of balance and such arrangement without counterbalance would be out of the question. It therefore becomes necessary in the two-cylinder engine either to fit counterbalance weights on the crank shaft, involving their extra weight and expense, or to adopt the arrangement of Fig. 11 with its irregular distribution of power strokes through the complete cycle. The latter is the arrangement usually adopted by builders of the two-cylinder four-cycle type of engine.

In a similar manner it is seen that if we combine four cylinders successively one stroke apart, as indicated in Fig. 12, we shall obtain a power stroke in one cylinder or another for every stroke of the engine. It is also seen that the cranks will all lie in one plane, those for (*a*) and (*c*), for example, being up with their pistons at the top of the stroke when those for (*b*) and (*d*) are down with their pistons at the bottom of the stroke. So far as turning effort is concerned it is seen that this arrangement of cranks is equivalent to a single-cylinder steam engine with steam acting in the usual manner on both sides of the piston.

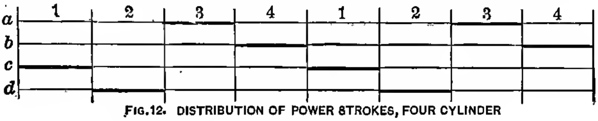

FIG. 12. DISTRIBUTION OF POWER STROKES, FOUR CYLINDER FOUR CYCLE ENGINE WITH ALL CRANKS IN ONE PLANE.

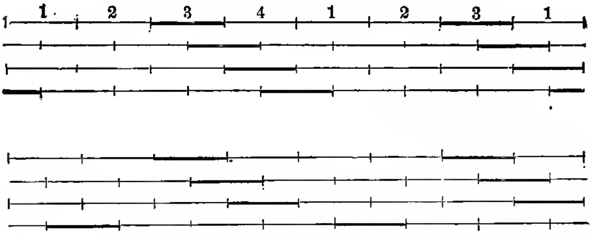

FIG. 13. DISTRIBUTION OF POWER STROKES, FOUR CYLINDER FOUR CYCLE ENGINE WITH CRANKS AT 90 DEGREES.

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The question naturally arises regarding the distribution of power strokes in the case of four cranks at right angles successively around the circumference, as in the common type of four-cylinder marine steam engine. There might be several arrangements, of which two are indicated in Fig. 13. The successive strokes follow at intervals of one-half stroke between cylinders, corresponding to the 90 degree crank angle, and it is seen that the power strokes, indicated by the heavy lines, overlap in amounts varying with the arrangement, thus concentrating the power into a certain part of the entire cycle and leaving the remainder without turning effort. From this viewpoint, therefore, all such arrangements are inferior to that indicated in Fig. 12.

With the two-cycle engine the combinations are similarly shown in Figs. 14, 15. In the former with cranks opposite the power strokes alternate between the two cylinders, so that on one or the other there is a power stroke for every stroke of the engine. This combination is therefore equivalent to the four-cylinder four-cycle arrangement indicated in Fig. 12, or to the common single-cylinder steam engine.

In Fig. 15 the arrangement with cranks at 90 degrees is shown.

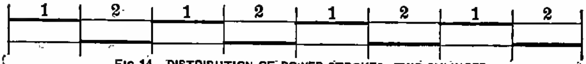

FIG. 14. DISTRIBUTION OF POWER STROKES, TWO CYLINDER TWO CYCLE ENGINE WITH CRANKS OPPOSITE.

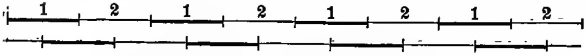

FIG. 15. DISTRIBUTION OF POWER STROKES, TWO CYLINDER TWO CYCLE ENGINE WITH CRANKS AT 90 DEGREES.

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It is clear that here the power strokes overlap for a half stroke in one part of the cycle, leaving an equal period in another part without power or turning effort. The correct arrangement as regards turning effort is therefore that indicated by Fig. 14 with the cranks opposite.

It is also of interest to note that the equivalent of a two-cylinder steam engine with cranks at 90 degrees would require an eight-cylinder four-cycle or a four-cylinder two-cycle engine, the former being arranged in two groups of four cylinders each, and the latter in two groups of two cylinders each, all cranks in one group lying in the same plane, and the plane of the two groups lying at 90 degrees with each other.

Engines with three and with six cylinders, and with cranks at

120 degrees, are also found in the practice of the day. These permit of an excellent running balance and of a very satisfactory distribution of crank effort throughout the revolution. Various arrangements of power stroke are possible, but the most satisfactory are indicated in Figs. 16 and 17 respectively for the two- and four-cycle types.

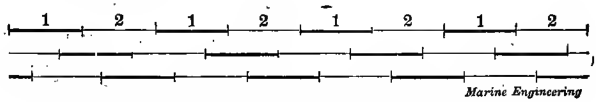

FIG. 16.—DISTRIBUTION OF POWER STROKES, THREE-CYLINDER, TWO-CYCLE ENGINE, WITH CRANKS AT 120 DEGREES.

General Comparison. In a general comparison between the two- and four-cycle engines the following points may receive consideration:

(*a*) For a given size of cylinder, length of stroke, and revolutions per minute, the two-cycle engine will give more power than the four-cycle. If the same amount of gas of the same quality could be burned in each cylinder and if the energy de-

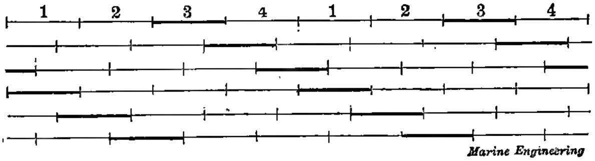

FIG. 17.—DISTRIBUTION OF POWER STROKES, SIX-CYLINDER FOUR-CYCLE ENGINE, WITH CRANKS AT 120 DEGREES.

veloped could be used with the same efficiency, or in other words if the gas could be used with the same thermal and mechanical efficiency in both engines, then, since the two-cycle engine gives twice the number of power strokes in the same time, it is clear that it would develop twice the power of the four-cycle. Actually, however, the ratio is slightly less than two to one, varying with the special circumstances of the case. Under reasonable conditions, however, the two-cycle engine may be depended on to give from 75 to 80 or 85 percent of power in excess of the four-cycle for the same size and revolutions.

The failure of the two-cycle engine to develop under like conditions fully twice the power of the four-cycle is due chiefly to the difference in the control over the mixture in the cylinder. The waste gases are chased out of the cylinder in large measure by the incoming fresh gas, and this cannot be accomplished without some intermixture of the two, and this must result either in undue dilution of the charge if the exhaust is closed too soon or in the escape and wastage of part of the fresh gas if the closure of the exhaust is delayed. In the general case, therefore, the quality of the gas mixture is not under as definite control in the two-cycle as in the four-cycle engine, and this will react unfavorably on the amount of work which can be obtained per power stroke. During the non-power strokes the work involved in what may be termed handling and preparing the gas for the power stroke is presumably about the same in both tyes of engines.

As regards engine friction the two-cycle engine has somewhat the advantage over the four-cycle. In the former the friction of two strokes is charged against the power stroke, while in the latter the friction of four strokes must be thus charged. It results that in the latter as compared with the former the friction of two extra strokes must be charged against the one-power stroke of the complete cycle.

As a combined result of these various relations, the two-cycle engine shows, as above stated, an advantage in power developed of from 75 to 85 percent for the same size of cylinder and revolutions per minute.

It follows, of course, that for a given power required the two-cycle engine will show a marked saving in weight and space occupied as compared with the four-cycle type.

(*b*) With engines of the same general size and working under the same general conditions, the four-cycle type is found to be somewhat more economical in operation than the two-cycle. This means more power per cubic foot of gas, or per pound or gallon of fuel. This superiority is due primarily to the more perfect control over the quality of the mixture in the cylinder, and the more perfect thermal cycle for the gas in one case than in the other, and as discussed above in reference to the relation between the amounts of work in the two types of engine.

(*c*) Speed variation is somewhat more easily controlled with the four- than with the two-cycle engine. The various ways of effecting such control will be referred to at a later point, but in this general comparison it will be fair to point out that for widely varying speeds the four-cycle type will be found the better adapted. This again is due to the more definite character of the operations in the four-cycle type, and to the better control which may thus be exercised over the resultant charge of fresh gas.

(*d*) A more uniform turning moment may be obtained from the same number of cylinders working on the two-cycle plan than on the four-cycle plan. This will be readily seen by referring to the preceding discussion of power strokes and turning effort in multi-cylinder engines.

(*e*) A somewhat smaller flywheel is required with the same number of cylinders working on the two-cycle plan as compared with the four-cycle plan. This follows from the more uniform turning moment as noted in (*d*) above.

(*f*) The two-cycle engine more readily gives a combination of smooth turning moment and running balance. This will be readily seen by a detailed comparison of multi-cylinder engines using the graphic method of Figs. 10-17.

(*g*) High revolutions, if desired, are somewhat more readily realized and regularly maintained with the four-cycle than with the two-cycle type.

(*h*) The general trend of engineering opinion and practice justifies the conclusion that the four-cycle type is on the whole to be preferred for engines of any considerable size or power or when economy of operation is of special importance, or where very high speeds of revolution are desired, and in general with reference to durability, reliability, and certainty of operation and control. On the other hand there is an undoubted field for the two-cycle engine in small sizes and where light weight, compactness, simplicity, and low cost of construction are considerations of special importance.

Having thus considered the general character of these two types of marine internal combustion motors, we shall, in the next chapter, take a nearer view of such motors as they are actually found in the leading practice of the day.

THE MOTOR-BOAT ENGINE.

The problem of the engine, or of the motive power, as already outlined in the introduction, will involve questions of weight and space, economy, simplicity, reliability, adaptation, and cost. In addition to these general considerations and in a more detailed way there will be questions of proportion, size, and form, of material and workmanship, of carburetion and ignition, of lubrication and wear, and, in short, of the many points of detail which lie between the engine as it exists in the mind of the designer and in the boat of the user. The general structural arrangement of the marine internal combustion motor of the two-cycle type is well indicated in Figs. 18 and 19, showing sections through an engine of the *Western* design, while in Fig. 20, showing a section of an engine of "Standard" design, the general arrangement of a single-cylinder four-cycle engine is likewise indicated. In either case multi-cylinder engines will require, of course, only a reduplication of similar units. An examination of these cuts in connection with the discussion of the operation of the two- and four-cycle type of engine, as found in the introductory chapter, will serve to make clear the function of the various parts here shown, and also to still further illustrate the same general principles and theory of operation. The cuts further illustrating the present article, and drawn from representative examples of modern design, will also serve to illustrate many general points of arrangement and design outside of those to which direct reference may be made.

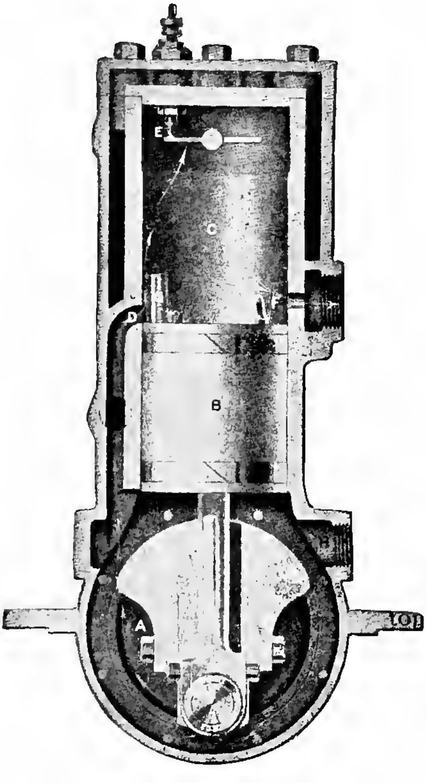

FIG. 18.—SECTION OF "WESTERN" TWO-CYCLE ENGINE.

Weight. Turning now to some of the special features which go to make up the problem of the engine, we find weight standing near the top in point of importance. This question has already been touched on in connection with the general discussion of the two- and four-cycle types, and it will be remembered that with

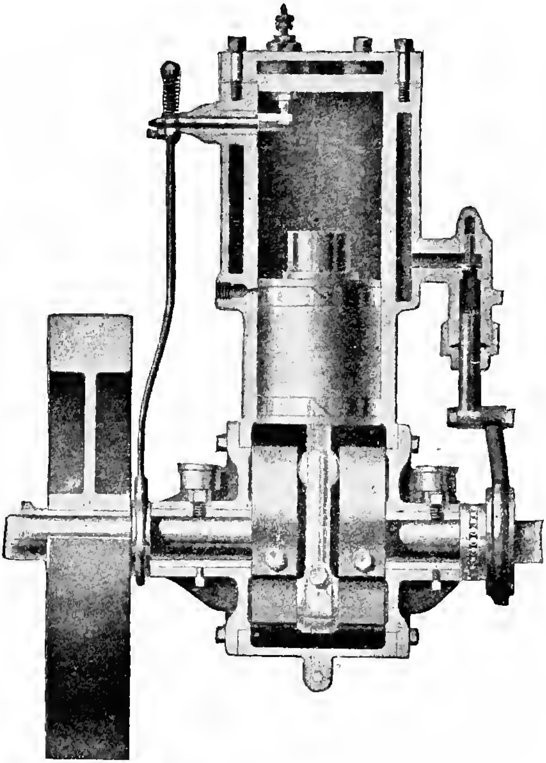

FIG. 19.—SECTION OF "WESTERN" TWO-CYCLE ENGINE.

the same general schedule of design the four-cycle type will be somewhat heavier than the two-cycle. Pursuing this comparison with reference to some further points of structural detail, it is clear that with the two-cycle engine the necessity of inclosing the crank case will involve a certain amount of weight which is saved in the four-cycle type, and the latter may in consequence be made sensibly lighter per cylinder so far as columns and bedplate are concerned. On the other hand, the four-cycle type must be made somewhat heavier in its valve gear and flywheel. The difference due to these items, however, will scarcely balance the relative gain due to crank case, and it thus results that per cylinder and on the same general schedule of design the four-cycle type may be made somewhat lighter than the two-cycle. On the basis of power the two-cycle type scores its most important advantage

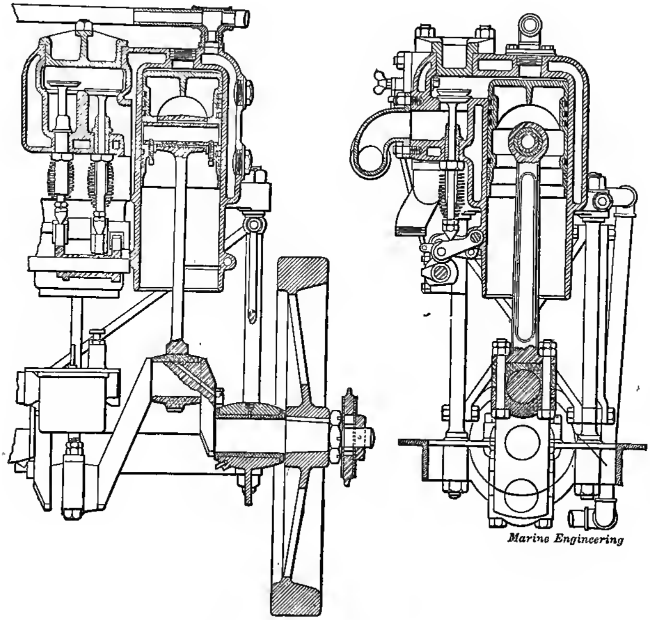
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FIG. 20.—SECTIONS OF "STANDARD" FOUR-CYCLE ENGINE.

by reason of the double number of power strokes in a given time, and in consequence of which (with all other conditions the same)

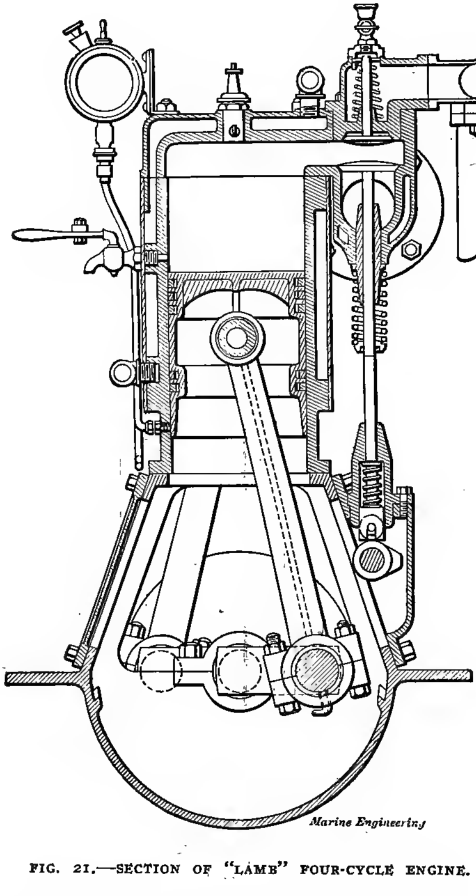

FIG. 21.—SECTION OF "LAMB" FOUR-CYCLE ENGINE.

the power developed in the two-cycle type would be twice that in the four-cycle. This advantage is discounted, however, by the higher revolutions practicable with the four-cycle type, and by the somewhat higher thermodynamic efficiency of its cycle, as already noted.

On the final power basis these various relative gains and losses are likely to leave the advantage slightly with the two-cycle type, comparing on the same general schedule of design. So far as actual practice goes, however, the four-cycle type scores a signal advantage in having attracted much more attention and study on the part of engineers and skilled designers, especially for engines of moderate to large power. It thus results that in the best practice of the day with four-cycle engines, every advantage is taken of special materials and of their most economical disposition and use, and all in such manner as to realize the needed strength on the minimum of weight and space. Large engines, furthermore, gain in economy of weight per unit of power, so that with the best practice of the day, four-cycle engines in typical sizes, or from 10 to 100 horsepower and upward, are very much lighter

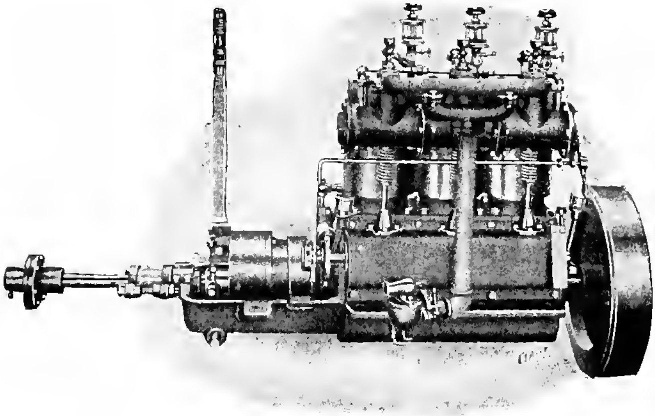

FIG. 22.—THREE CYLINDER, FOUR-CYCLE "LAMB" ENGINE, STARBOARD SIDE.

per unit of power than two-cycle engines, also in typical sizes, or from 2 to 10 horsepower.

Between the two types of engine there is, after all, but little contest so far as possession of the field is concerned. For engines of moderate to large size, and where economy, reliability, and durability are of importance, the four-cycle type must be conceded to be typical; while on the other hand for small sizes, and where compactness, simplicity, and low first cost are of importance, the two-cycle type may properly claim full recognition.

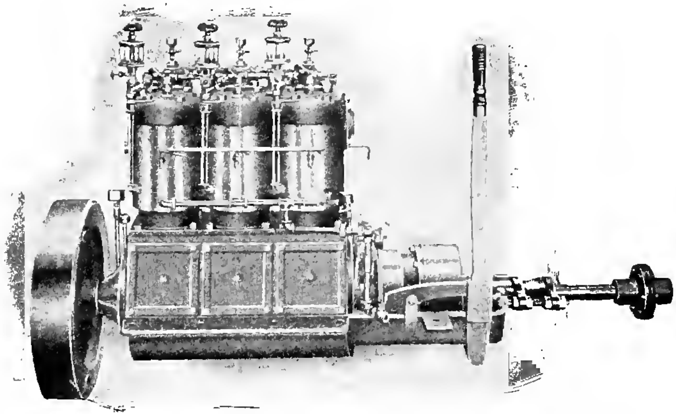

FIG. 23.—THREE CYLINDER, FOUR-CYCLE "LAMB" ENGINE, PORT SIDE.

In moderate or large sizes, or from 10 horsepower to 100 and over, four-cycle engines are quoted from an upper range of 60 or 80 pounds down to 10 pounds or less per horsepower, lighter as the size of the unit increases, and according to the style of design. To a certain extent there is coming to be a differentiation in the field of design into common and so-called "auto" or high-speed practice. In the latter the weights may be expected to vary from perhaps 20 pounds per horsepower down to 10 or less, while in the former the ordinary range is found perhaps between 40 and 80, or even up to 100 and over in small sizes. For two-cycle engines the weights in sizes from 1 to 5 horsepower are found usually between 50 and 100 pounds per horsepower. These figures again illustrate the fact above noted that the field of operation is fairly well divided between the two types, the two-cycle being found only in small sizes, and the four-cycle being restricted for the most part to medium and large sizes; and that while on the same schedule of design and in the same sizes the two-cycle engine may be made somewhat lighter, actually the lighter constructions are in the four-cycle type because the schedules of design and the sizes are not the same, and the four-cycle type gains in marked degree both by reason of its size and the special design in which such engines are made when high speeds are desired.

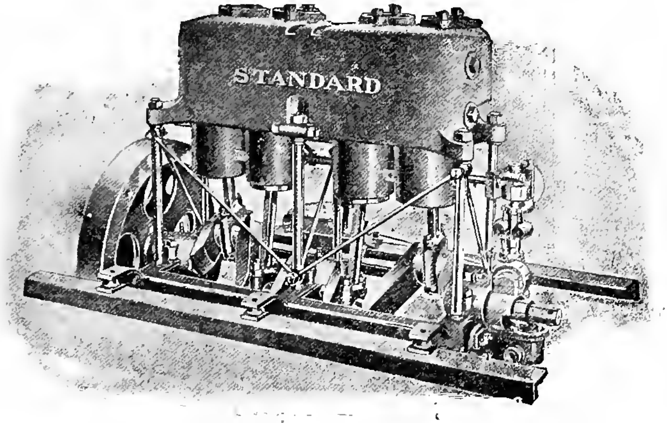

FIG. 24.—FOUR CYLINDER, FOUR-CYCLE "STANDARD" ENGINE.

In quoting the weights of engines there is much diversity with regard to including the weight of the flywheel. It is clear that with so considerable an item either omitted or included, a very considerable difference will result in the weight, and in order to

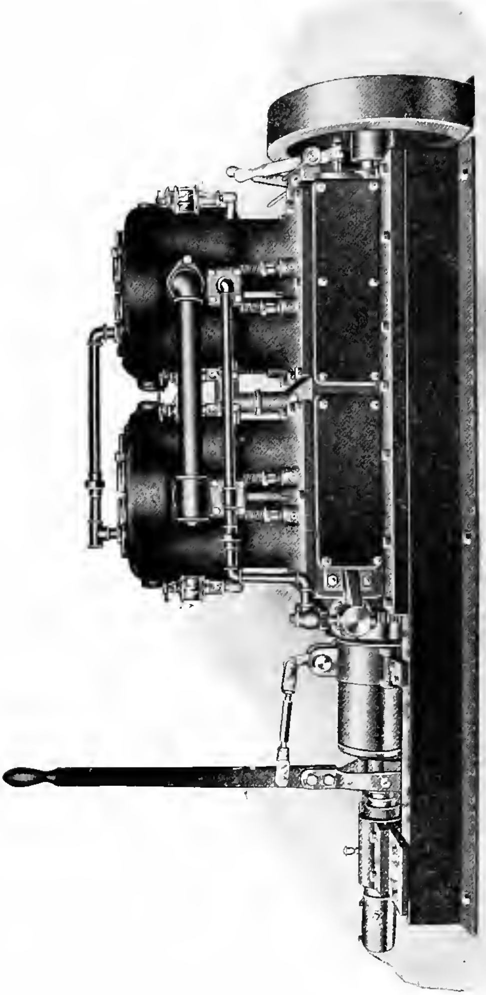

FIG. 25.—FOUR CYLINDER, FOUR-CYCLE "EAGLE" ENGINE.

properly interpret any given figures it should be definitely known whether they include the flywheel or not. Since it is a necessary

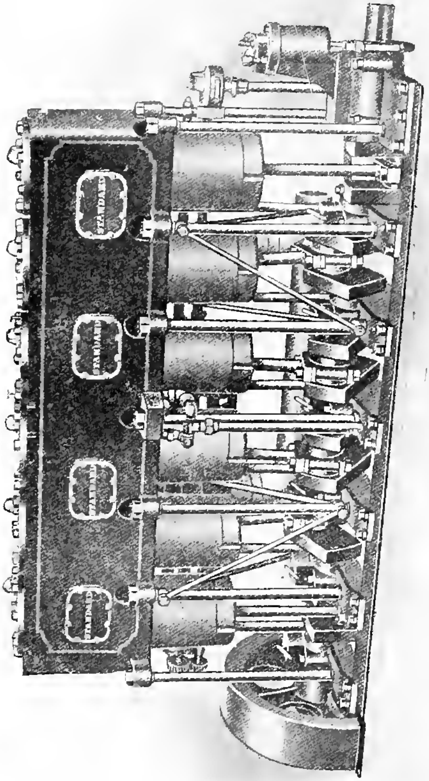

FIG. 26.—SIX CYLINDER, FOUR-CYCLE "STANDARD" ENGINE.

feature of the operation of the engine it should, of course, be included.

Details of Design. The limits of the present series of articles will not permit of any general discussion of the problem of design.

There are, however, certain special points to which brief reference may be made.

We first note, as shown in the various cuts, that the typical marine internal combustion engine is of the single-acting type with half-trunk piston, thus avoiding the use of the usual crosshead connection between piston and crank. This mode of connection, as well as the need of broad rubbing surfaces, gives to the piston its typical form, so distinctly different from the shallow piston employed in the common type of steam engine. This again leads to the long cylinder bore met with in all engines of this type. The relation between stroke and diameter is very commonly one to one, while occasionally the stroke is slightly greater than the diameter. The actual length of cylinder, however, including the length of piston and length for the clearance in which the gases are compressed, is very commonly between two and three times the diameter of the bore.

In the two-cycle type the frame and bedplate are very commonly cast together with the cylinder, the casting containing likewise the inlet and exhaust passages and cylinder-jacket space. In the four-cycle type the cylinder frame and bedplate are also in some cases either cast together or are constructed of cast metal mounted up as a solid structure, and as shown in several of the illustrative cuts. In other cases, where saving of weight is of importance, the framing is made of light steel columns, very similar in style to the so-called torpedo-boat type with the steam engine, and as shown in Fig. 27.

The form of the piston has already been referred to. In all first-class designs special attention is given to the piston packing. Usually two sets of spring rings are fitted, one set near each end, and two or three rings in each set. Leaky piston rings, in addition to the direct loss by leakage on the power stroke, seriously disturb the operation of the engine by preventing proper compression, and thus interfering with the efficiency and completeness of combustion. For these reasons the piston packing is a matter of serious moment, and one to which designers and builders must give special care, and users must endeavor to maintain by careful lubrication and general watchfulness.

In the matter of the moving parts generally, modern practice has made great advances, both in form and proportion and in the materials employed. Large power on small weight means special care in the disposition of material, and special provision in the size and proportion of joints and rubbing surfaces. A comparison

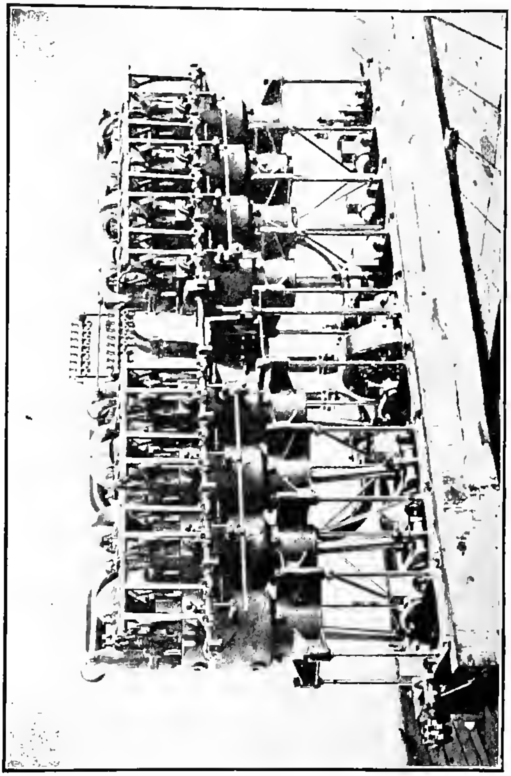

FIG. 27.—EIGHT CYLINDER, FOUR-CYCLE "CRAIG" ENGINE.

between the sizes and proportions of the crank pins and main shaft bearings under present conditions, and those prevailing in the practice of a few years ago, will show one of the principal means by which the present extreme results are obtainable. Special bronzes of tensile strength running to 70,000 or 80,000 pounds per square inch, and special steels running to 140,000 or 150,000 pounds, are used for rods and shafting, especially in the leading European practice with designs for forced output.

Turning to valve gear, in the two-cycle type there are no valves for distribution to the engine, and only such valves are required as may serve to control the supply of gasoline to the carburetor, or to serve as throttle between the latter and the crank case. This item makes for simplicity and is one of the principal features tending toward lower first cost in this type of engine. In the four-cycle type each cylinder must be fitted with an inlet and an exhaust valve. These are commonly of the disk or poppet form and are usually of about the same size and in some cases interchangeable. The inlet valves are made either automatic in operation or driven by a suitable gear. The automatic valve operates in manner exactly similar to the valve of an ordinary pump, opening when the pressure within the cylinder falls below that within the carburetor, and closing when it rises above. For moderate revolutions such mode of operation will be found entirely satisfactory, but for distinctively high speeds the positively driven valve will be found more definite and satisfactory in its action. The general type of positively-driven gear consists of a revolving shaft geared down so as to make one complete revolution for two of the engine, and carrying cams suitably arranged for the operation of the valves. One shaft may thus be used for the operation of both the inlet and exhaust valves. In the best practice water jackets surround the valve chambers and valve-stem guides, thus preventing overheating and insuring a smooth and easy working valve. The valves should be readily accessible for examination or renewal, and this requirement is usually realized by placing them in pockets covered by removable bonnets or caps. A typical arrangement of valves and valve gear with automatic inlet valve may be further illustrated by the section of Fig. 20, and a careful examination of this figure will sufficiently illustrate the main features of this general type of gear.

Regarding the item of thrust bearing, the ball bearing form for small and moderate sizes has received favorable notice, and has gained a definite status in the practice of the day. In larger sizes special forms of roller bearing are employed to some extent, while the familiar form of ring and collar thrust is still preferred by most designers.

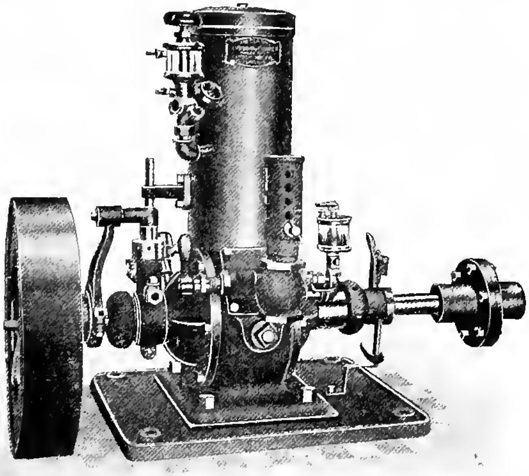

FIG. 28.—SINGLE CYLINDER, TWO-CYCLE "LAMB" ENGINE.

Ignition. For the purpose of igniting the charge, present-day practice is divided between the so-called "make-and-break" or contact spark, and the jump spark. In the former the spark is formed between two metallic points in the circuit of a spark coil, which are brought together and then "broken" or quickly separated. The jump spark, on the other hand, is formed between two stationary points which are in the circuit of the secondary of an induction coil. Contact being then made in the primary coil at the proper instant in the stroke a stream of sparks plays between the two terminals on the secondary circuit located within the cylinder and separated by a distance of about $\frac{1}{16}$ inch. The contact spark requires moving parts within the cylinder, while the jump spark does not. With both forms trouble may arise due to corrosion or wear on the points, or to their becoming covered by deposits of a gummy carbonaceous matter. In special designs of make-and-break devices various means are in use to provide or permit a gradual shifting of the actual sparking surfaces, so as to distribute the wear over a considerable surface and thus increase the durability of a given set of "points." With both forms of device the time at which the spark shall pass relatively to the position of the piston may be varied by an adjustment of the connections controlling the operation of the sparking gear. It is usually claimed by the advocates of the "jump" system that this adjustment is more readily effected than by the "make-and-break" system, and that the resultant speed range is wider; and also that the sparking points carried in an easily removable plug are more readily examined or replaced. There seems to be foundation for this claim and it must be admitted for most cases of high speeds and large power, as well as where readiness of handling and range of speed are of importance, that the jump spark is usually employed.

Cooling. Due to the high temperature of the products of combustion, the walls of the cylinder tend to become heated beyond the point of practicable lubrication, resulting in the rapid cutting and scoring of the bearing surfaces of the piston and cylinder. To prevent this the excess heat in the metal is removed by surrounding the working parts of the cylinder by a water jacket, as indicated in the various cuts. In the best practice of the day provision is made for independent expansion between the inner cylinder or liner and the outer cylinder or barrel, in order that the former may expand and contract without constraint from the latter. In many cases of excellent design, furthermore, the jacket is made by a brass shell fitted over the cylinder casting, which is accurately turned on both inside and outside, thus insuring uniformity of thickness in both parts of the structure, uniformity of temperature about the entire circumference of the cylinder, and, in consequence, a true circular form—a result scarcely possible with a cast-iron structure in one casting, with its inevitable

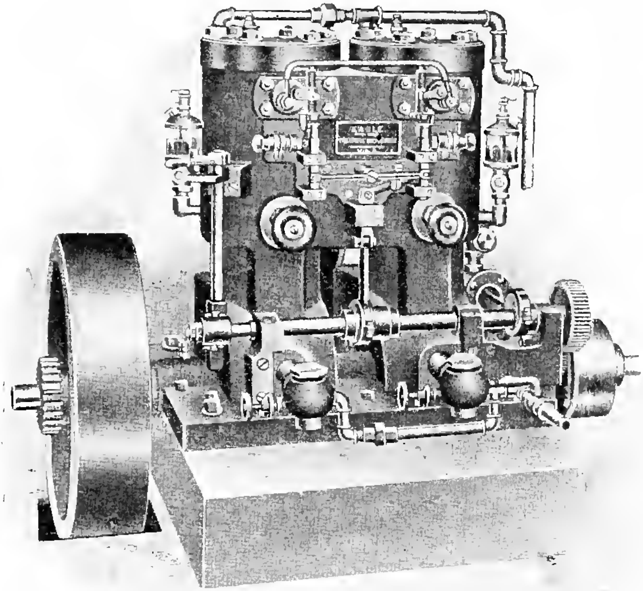

FIG. 29.—TWO CYLINDER, TWO-CYCLE, 10 H.P. "EAGLE" ENGINE.

variations in thickness from one point to another. The cooling water is usually provided by a small reciprocating plunger operated by an eccentric on the main or valve cam shaft. In some cases, however, rotary pumps have been used with good results. It may be noted at this point that it is possible to carry the cooling action too far as well as not far enough. In the latter case there is, of course, danger of mechanical injury to the piston and cylinder. In the former too much heat may be removed from the cylinder, and its efficiency as a heat engine may thereby be decreased.

Lubrication. For lubrication of the crank pin, designers of the two-cycle engine have found the splash system a simple and effective means. The bottom of the crank case is filled with oil to such a point that the crank will splash the oil as it goes around, and thus receive a supply of lubricant. The same general source is also usually depended on to supply lubricant for the piston and for the upper end of the connecting rod as well. The chief objection to this mode of lubrication is found in the fact that the charge of vapor passing from the crank case to the cylinder will carry with it some small amount of lubricating oil. This in the cylinder will become burned, producing a charred or semi-viscid residue, which in time may clog the passages or cover the sparking points. Due to this fact some of the most recent designs show special means for oiling the cylinders and the parts within the crank case at stated times or at will, and by special adaptation of the means commonly employed in general engineering practice. For the other bearings and moving parts of the engine, compression grease cups, sight feed cups, and other similar means common to the engineering practice of the day are employed.

Speed Control. For purposes of speed control some combination of two general means is employed. These are:

(1) Control by throttling the amount of mixture introduced per stroke, and hence of the resulting work which can be developed.

(2) Control of the instant of sparking relative to the position

of the piston, thus modifying the power which will be developed by a given charge. Reference to the form of indicator card given in the introductory chapter and to the description of the operation of the engine will show that at some one point the card corresponding to a given charge will have the largest possible area. Retarding the spark beyond this point will then give a card of which Fig. 30 may be taken as a typical illustration. In some cases use has been made of an impoverishment of the mixture by increasing the amount of air. This, however, is not to be recommended, as it is less certain and satisfactory than a suitable combination of throttle and spark control.

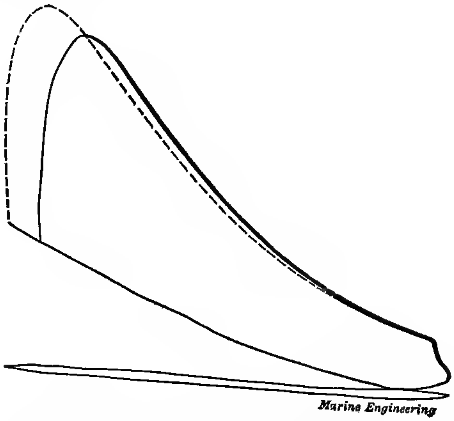

FIG. 30.—INDICATOR CARD WITH RETARDED SPARK. DOTTED LINE SHOWS NORMAL CARD.

In cases where the engine is connected to the propeller shaft through a reversing clutch, and where in consequence the engine may be running without load, the throttle, in the best designs, is placed under the control of an automatic governor of the centrifugal type, thus placing the speed under limitation with any and all conditions. Where the engine is multi-cylinder and of the so-called reversing type, the engine is connected direct to the propeller shaft, and is thus under load at all times. In such cases the engine is therefore controlled by hand throttle as in the steam engine.

Reversing and Handling. For reversing the thrust of the propeller with the internal combustion marine motor there are three methods at hand:

(1) Reversing the obliquity of the propeller blades.

(2) Reversing the direction of rotation of the propeller shaft by a mechanical reverse located between the engine and the shaft.

(3) Reversing the direction of the engine itself.

Further reference to Number (1) will be deferred to the general topic of the propeller.

The mechanical reverse gear is usually some form of the well-known "box of gears" or "jack-in-the-box" type. It operates in such manner that when in the go-ahead motion the engine is coupled direct to the propeller shaft, and the entire arrangement operates as a solid coupling, and, of course, without waste of power. When in the reverse motion, the engine drives the shaft through the gears, by the operation of which it is reversed in direction, and with the resulting slight loss due to the friction and wear in the gears. For engines of small or moderate size this form of reverse has generally commended itself to designers, and in one form or another is quite commonly employed. In large sizes, however, it is preferable to reverse the engine itself, as in the steam engine, and in certain cases of recent design the reverse is effected in this manner. It is clear that an internal combustion engine is as ready to run in one direction as the other, and that it requires only the proper adjustment of valve gear and sparking instant, together with an initial impulse, to start in either direction. In such form of reverse, then, the angular position of the cams operating the valves and the spark advance are both under lever control in such manner that from a mid-position the lever may be moved in either direction, thus placing the valves and spark in suitable relations for operating in one direction or the other according to the position of the lever. The initial impulse may then be obtained in the usual manner for starting and the engine will continue in the same direction.. While this mode of reverse requires some additional features in the mechanism of the valve gear, still it must be considered as the most satisfactory in general principle, and in operative detail, except perhaps for engines of the smallest size. It may be added, however, that in order that this mode of reverse may be able to demonstrate its full value for rapid backing and filling, it should be used in connection with an auxiliary starting arrangement of some effective type. A typical arrangement of this character includes a small auxiliary air-compressor pump and receiver, with throttle and connections, with the compression space in the cylinders of the engine. At the will of the operator the compressed air may then be turned into the cylinder or cylinders just near or beyond the point of maximum compression, and thus the engine may be started as readily and in the same manner as with steam. The compressor may be so arranged as to throw in or out of gear when desired, and the receiver may readily be made of sufficient capacity to serve for starting the engine from 20 to 30 times. In the handling of engines of smaller size where the auxiliary compressed-air receiver is not fitted, recent practice shows various improvements in detail, such as the provision of a lever for reducing the compression when turning by hand, retaining just sufficient to insure ignition. Manipulation of this lever to reduce the compression serves also to retard the spark, so that there can be no "kick back" or danger to the operator when "cranking" by hand.

Muffling. Great improvements have been made in recent years in connection with the decrease of the sound occasioned by the exhaust. In principle the muffler operates by splitting up the individual puffs, in part mechanically and in part by the acoustic influence of an intermediate chamber, in such manner as to dissipate and absorb the sound energy of the exhaust and reduce the succession of sharp exhaust puffs into a more nearly constant and gentle discharge. It is not practicable to realize the full beneficial effect of the muffler except by some increase in the back pressure against which the engine exhausts, and in cases where the maximum power is an absolute necessity the muffler should be cut out and the noise accepted as the price to be paid for the additional power. To permit of this the muffler should be so installed that it can be readily cut in or out, and in both cases the exhaust leads should be direct and free in order to reduce the back pressure to a minimum.

Economy. The matter of economy is little thought of in connection with the typical engines used in small runabout boats, but with those of larger size—from 20 horsepower upward for example—the question of economy will affect in a serious manner both the expense of operation and the radius of action. It is for these reasons among others, as already noted, that the four-cycle engine, with its superior economy, is preferred for such cases. The formula very commonly quoted with reference to the economy of internal combustion motors using gasoline is "one pint per horsepower hour." This is better than two-cycle engines can be depended on to give, and small four-cycle engines will not give any such figures except with care and under the best conditions. One pint per horsepower hour means good conditions with the four-cycle engine of moderate to large size. At the same time, with special care, this result may be slightly bettered, while on the other hand but slight departure from the conditions for best operation will serve to carry the consumption above this figure. Economy with an internal combustion engine depends on the following chief conditions:

(1) The proper proportion of air to gasoline vapor: *i.e.*, the proper quality of the charge.

(2) A proper degree of compression.

(3) Prompt ignition and complete combustion.

(4) The highest practicable degree of expansion on the power stroke.

(5) Only such an amount of cooling by the water jacket as may serve to keep the surfaces of cylinder and piston in good working condition.

(6) Valve ports of sufficient area to insure prompt and full admission and release.

With these various conditions fulfilled in good degree, and with engines of fair to large size, a consumption of one pint per horsepower per hour may be counted on with confidence, but with neglect of the proper precautions, and in small sizes especially, the consumption may rise to twice this amount, or more.

Carbureter.—The carbureter occupies toward the gasoline engine a relation entirely different from anything found in the steam engine or its operation. The fuel comes to the engine in the form of a liquid. Before it can be burned it must be brought to the condition of vapor mixed with a certain amount of air. It is the function of the carbureter, or vapor generator, as it is sometimes termed, to thus prepare the liquid fuel for combustion as a vapor in the engine. The importance of the carbureter and of its operation cannot be overestimated, and it is not too much to say that of the various troubles with the gasoline engine, by far the largest part are caused directly or indirectly by imperfect carburetion. The fundamental requirements for a carbureter are as follows:

(1) To produce a mixture of vapor and air within narrowly varying proportions of each.

(2) To produce such mixture independent of the speed of the engine or the temperature of the atmosphere.

(3) To use up completely the gasoline fuel, and not merely the more volatile portions, as in certain early forms.

The fundamental principle on which all carbureters operate involves the intimate mingling of gasoline and air under conditions suitable for vaporization. Vaporization is always a surface phenomenon; that is, a liquid can evaporate only at a surface which is in contact with air. The real problem consists, therefore, in bringing large surfaces of gasoline and air into contact, and under a temperature suitable for the evaporation of the former. This has been brought about in various ways. Early forms have consisted essentially of means for spreading out the gasoline in a thin layer or film and passing the air over it on its way to the engine cylinder. A further extension of this idea includes a series of wicks or layers of fibrous material in which the gasoline rises by capillary attraction and thus becomes exposed in large surfaces to the entering current of air. A variety of arrangements in detail are met with but in all cases the same underlying principle is found—the spreading out of the gasoline into a thin film exposed to the stream of inflowing air.

In a different and later type of carbureter air is allowed to bubble through the gasoline, absorbing vapor on its way and thus accomplishing the same general purpose. This constitutes in effect a fine subdivision of the air with correspondingly large surface in contact with the body of gasoline through which it is passing on its way to the engine. Many forms in detail have embodied this principle, later developments including a float arrangement for insuring a constant level and a uniform depth of gasoline through which the air passes.

The fundamental objection to carbureters of these two forms lies in the fact that the vaporization is selective. It is readily seen that under the conditions described the more volatile portions of the gasoline will be first vaporized, leaving the heavier portions behind and causing a continuously increasing density in the residual liquid. This will tend to clog the wicks in forms using such appliances, and in all cases will gradually interfere with the operation of the apparatus as intended.

In order to obviate this fundamental objection, later forms of carbureter operate by means of a jet of the liquid fuel spurted into the stream of inflowing air. This operation gives first a mechanical spray directed into the stream of air, and this flashes quickly into vapor, thus achieving the purpose in view. By this method the fuel is vaporized completely and not selectively, and thus the body of gasoline remains of constant quality. The jet of liquid is produced by the suction of the piston on the indrawing stroke. This forms a partial vacuum in the cylinder and connecting passages, and in answer to this difference of pressure air rushes in through the air inlet, and a jet of liquid fuel likewise enters through the gasoline nozzle. Such carbureters fall into two classes, according to whether or not a constant level of gasoline is maintained at the nozzle. These general principles are illustrated in Figures 31 and 32. In Fig. 31 is shown in schematic form a typical arrangement of float-feed carbureter. The weight of the float is so adjusted to the density of the gasoline that with the liquid in the float chamber at the level of the jet nozzle *N*, the valve at the bottom of the float will be just closed. If the level of the liquid drops, the float will drop likewise, the valve is more widely opened, and the gasoline enters at an increased rate. If, on the other hand, the level should tend to rise above the level of the nozzle, thus producing a waste at the nozzle, the float rises

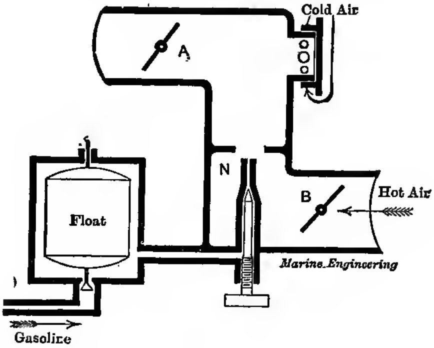

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FIG. 31.—FLOAT-FEED CARBURETER.

and closes the bottom valve tightly, thus shutting off the supply. In this manner the liquid is maintained always just at the mouth of the nozzle *N*, and ready to enter as a jet the instant the pressure is reduced by the in-stroke of the piston. The throttle *B* is provided to control the inflow of the air relative to the gasoline, and thus the richness of the mixture. The throttle *A* is provided to control the inflow of the mixture as a whole, and thus the power developed per stroke.

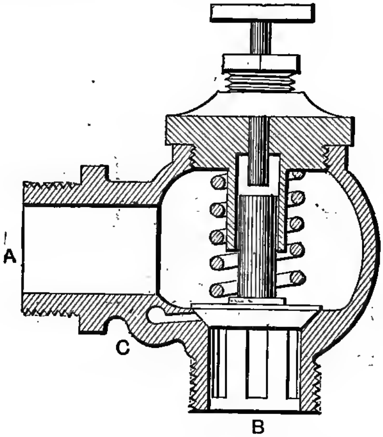

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FIG 32.—ANOTHER FORM OF CARBURETER.

In Fig. 32 is shown a simplified form in which no attempt is made to maintain a constant level of gasoline. The arrangement consists essentially of an angle-check valve. The opening *A* connects with the cylinder and the valve is kept seated by a light spring as shown. On the instroke the valve rises under the influence of the pressure resulting from the partial vacuum on the upper side, and air enters from *B*. The gasoline enters through an opening controlled by a needle valve, and fills a channel *C*, extending around the valve casing. From this passage several small openings connect with the seat of the valve, so that the opening of the valve results as well in the uncovering of these apertures, from which the gasoline enters and is caught by the stream of inflowing air as in other forms.

In certain other patterns of carbureter a constant level is maintained by pumping an excess of gasoline into a chamber, out of which it flows through the open mouth of an overflow pipe. This maintains a constant level even with the mouth of the overflow, and then combined with this may be fitted various arrangements of air inflow and gasoline-jet passage.

On the operation of the modern typical form of carbureter increase in revolutions per minute is accompanied by a decrease in the amount of air entering per stroke, with an increase in the suction head on the gasoline, combined with a decreased time during which such head can act. Without other adjustment, however, the proportion of air will become too small with extreme speeds of rotation, and the mixture will thus become too rich for the best results. To guard against this condition an auxiliary air inlet is often provided, which is opened automatically at high speeds. This is intended to maintain the proper proportion between air and gasoline nearly constant at all speeds of rotation.

THE BOAT.

The general problem of the motor boat has been already stated in the first of the present series of articles. Since this introductory development of the problem, as a whole, we have been concerned with the second of the three main divisions, the problem of the motive power.

We are to turn now to the first division as previously classified, the problem of the boat as to form and structure.

The problem thus approached naturally divides into two parts:

(1) The selection of such proportions and such form of hull, having due regard to carrying capacity, comfort, seaworthiness, etc., as shall insure the minimum resistance at the designed speed,

and thus permit of realizing such speed with the minimum power, or the maximum speed with a given power.

(2) With given form and dimensions and with due regard for strength, to construct the boat with the minimum weight of structural material, thus allowing the maximum share of the total displacement for carrying capacity and for machinery.

Taking all conditions at the extreme limit it follows that the motor boat of the highest attainable speed will show, on given dimensions, the lightest construction of boat consistent with the needed strength, a form suited to the highest speeds within the range of hope, and the maximum power developed on the fraction of displacement allotted to this purpose. For more moderate cases the boat may be made stiffer and stronger, fuller in form and with higher freeboard, giving greater roominess and carrying capacity (all conducing toward seaworthiness and general safety), combined with a generally heavier style of machinery construction conducing toward longer life and decreased expense for maintenance. These various desirable features are of course realized at the expense of some reduction in speed, and the result becomes a general compromise, as, in fact, all examples of engineering design of necessity are.

We shall postpone to a later point the discussion of structural features, and shall now proceed to a consideration of the factors which enter into (1) as above specified—the determination of such forms and proportions as will conduce to minimum resistance with an acceptable combination of other elements.

Resistance.—The resistance of any boat-formed body moving through the water may conveniently be divided into two parts: (1) The skin effect or so-called skin friction. This part of the resistance depends primarily on the extent and character of the wetted surface of the boat and on the speed, and increases a little more slowly than with the square of the speed.

(2) The wave effect or part which is manifested as surface disturbance. This part of the resistance depends chiefly on form,

proportion and speed, and varies with the speed by an index which lies usually between 3 and 4.

At low speeds the larger part of the resistance falls under class (1), and if low speeds alone were required, the form and proportions adopted would be such as to give a small wetted surface relative to the size of the boat. This would result in a relatively short, broad, deep model, rounded in form somewhat like an elongated hemisphere, and with a boat-formed bow and stern. As the speed advances, however, the wave-making resistance becomes more and more predominant, and at high speeds it takes first place, forming more than one-half the total resistance. If in some extreme case wave making could be imagined as the only form of resistance, the ideal boat form would be then reduced as nearly as possible to the proportions of a vertical plane. Such a boat would show an excessively narrow beam for the length, with knife-edge bow and stern. Actually, however, skin resistance is always present, and in any case a compromise is effected in accordance with the special circumstances in hand. Thus for moderate speeds a fairly large proportion of beam to length is permissible, with form moderately well filled out at bow and stern. As the demand for speed increases so must the proportion of length to beam increase, and coupled with increasing fineness of form at bow and stern, worked out in accordance with considerations to be discussed at a later point.

The actual proportions and form of a boat must, however, to some extent be determined in recognition of the internal space required for the proper installation of the machinery, while qualities relating to safety, seaworthiness, etc., demand likewise some recognition in the final combination. In particular, considerations of this character usually force the selection of a greater breadth of beam or greater proportion of beam to draft and length than would be otherwise selected for the higher range of speeds.

It may be well to note at this point that while the terms high speed and low speed are arbitrary in themselves, there are general

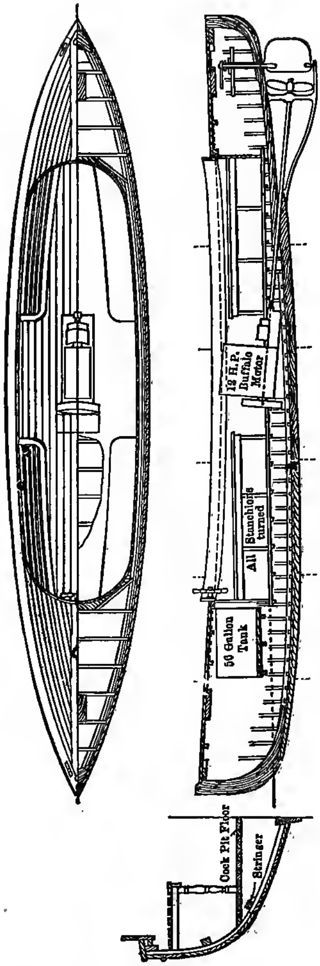

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FIG. 33.—INBOARD PROFILE, SECTION, AND PLAN OF A SMALL MOTOR BOAT.

limits in the relation of speed to length above and below which the terms high and low may fairly be applied. Roughly speaking, this limit measured in knots is close about the square root of the length in feet, higher as the beam is narrower and form

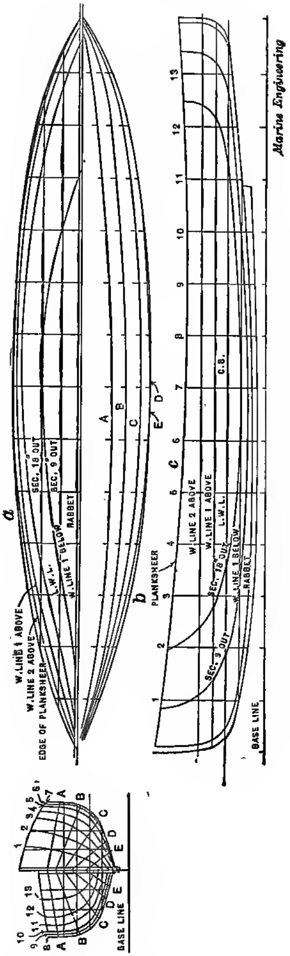

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FIG. 34.—LINES AND BODY PLAN OF A SMALL MOTOR BOAT.

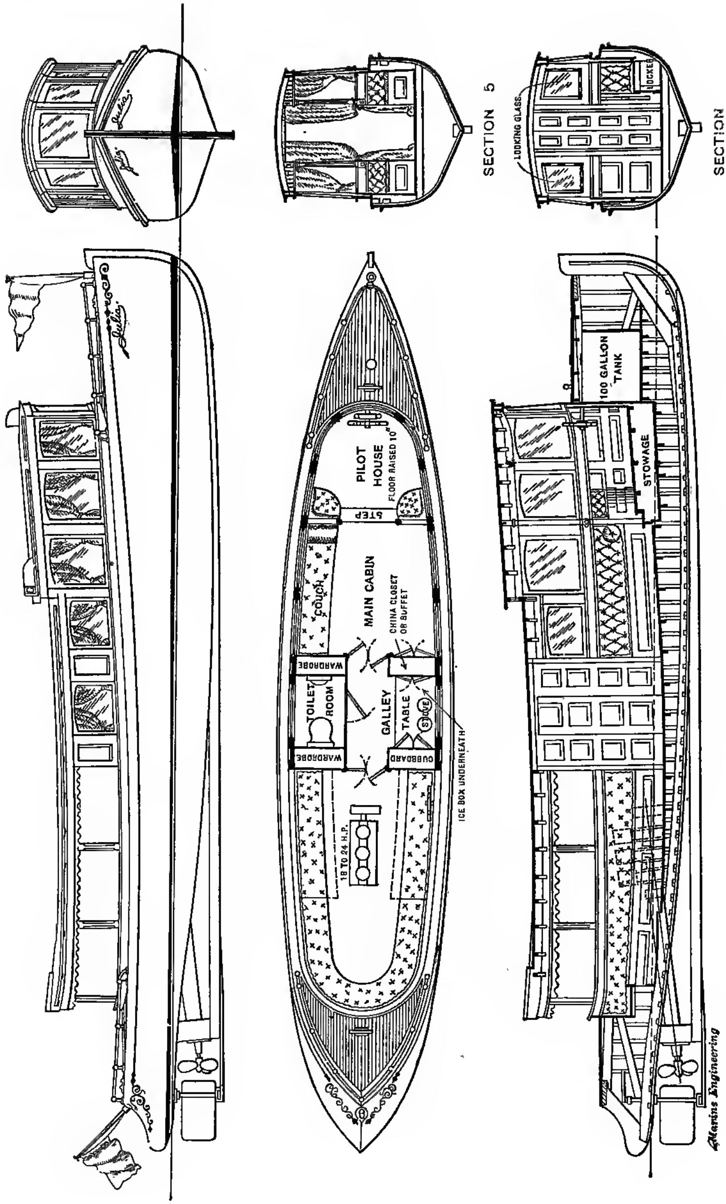
is finer, and lower in the inverse cases. Thus for a boat 25 feet long any speed above 5 to 6 knots will be high in the sense that wave-making resistance will be of some considerable importance, and the entire design of the form of the boat must be carried out with this fact in view. Likewise, for a larger craft 60 feet in length, speeds much above 8 knots or, perhaps, from 10 miles per hour upward, will produce such surface disturbance as to demand recognition in the design of form. From these proportions it is easily seen that practically all motor boats are run at speeds which are high in the sense in which the term is here used. Few boats are less than 16 or 18 feet in length, and for the average small boat up to 40 or 50 feet in length speeds of 7 to 9 or 10 miles per hour are considered the minimum acceptable.

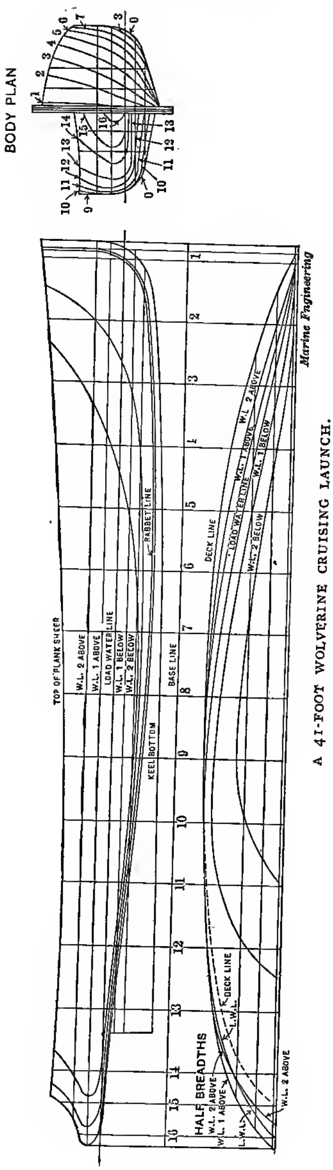
Referring again to the relation of length to beam, it is clear from what has been said above that so far as resistance alone is concerned the ratio of length to beam should increase continuously with increase in designed speed, and only for the lowest speeds can the lower values of this ratio be considered acceptable. Thus in the practice of the day actual values of this ratio are found between 5 and 10. The latter represents about the extreme value practicable under existing conditions regarding strength and space required for machinery. There is good reason to believe that still narrower boats would show excellent results at high speeds so far as considerations of resistance are concerned, but strength and room for machinery are obtained with continuously increasing difficulty as the beam is decreased in proportion to the length. Thus a boat 4 feet beam and 50 feet in length would doubtless show excellent results, so far as resistance is concerned, when pushed to speeds of 20 miles per hour or above, but such proportions would tend to render the boat flexible and, perhaps, unsafe in a seaway, and such beam would give quite insufficient width for the proper installation of the machinery suited to the development of the speed. In short, if the high speeds at which it is proposed to drive the boat might justify some such proportion of length to beam so far as resistance is concerned, the fact remains that the space demands of the machinery required to realize the speeds will not permit it. It thus results that ratios of 9 to 1 or 10 to 1 represent about the upper practicable limit under present conditions of engineering practice.

From these upper extremes we come down through all gradations to lower limits of 4½ to 1 or 5 to 1, found only in very short boats or in longer boats designed for low speeds, and which are intended to be roomy and large in carrying capacity or in which stiffness and safety in a seaway are of special importance. The general class of moderate-sized boats intended for fair speed, and with some consideration paid to matters of capacity and general comfort, show a length of 5½ to 6 or 7 beams. Lengths in excess of the higher figures indicate some special attention to high speed, and with other qualities sacrificed in some measure as the price to be paid for its attainment.

The proportion of beam to draft is of less relative importance, so far as resistance is concerned, than that of beam to length. Generally speaking, reduction in beam may go hand in hand with increase in draft, and thus the narrow, deep model forms a natural combination as well as its opposite, a broad, shallow form. For the usual type of motor boat it will be safe to select what may seem to be a suitable proportion of length to beam, and then allow the draft to be determined by the resultant weight conditions of the boat.

We may now turn to the question of the form of the boat, first for the underwater body and second for the part above the water-line. Naturally the characteristics of form will depend much upon the various other special requirements of the case, and especially upon that of speed. We may, therefore, with advantage take for first consideration boats of the highest speed and note the characteristics of form which tend toward its most effective realization. Naturally, furthermore, this is by no means a matter in which all opinions are in accord. Differences in both theory and practice exist among the best designers and builders growing out of different views regarding the relation of the various elements going to make up boat resistance, and


Julia
Julia
SECTION 5
LOOKING GLASS
LOCKER
SECTION
100 GALLON TANK
STOWAGE
PILOT HOUSE
FLOOR RAISED 10"
STEP
MAIN CABIN
COUCH
CHINA CLOSET OR BUFFET
WARDROBE
TOILET ROOM
WARDROBE
GALLEY
TABLE
STOVE
CUBBOARD
ICE BOX UNDERNEATH
18 TO 24 H.P.
Marine Engineering



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A 41-FOOT WOLVERINE CRUISING LAUNCH.

FIG. 35.—INBOARD AND OUTBOARD PROFILES, ACCOMMODATION PLAN, AND SECTIONS.

FIG. 36.—LINES AND BODY PLAN.

out of differences in experience in connection with problems of actual design. The following suggestions, however, contain the points generally agreed upon, and represent the general consensus of view regarding the best combination of form characteristics suited to the development of high speeds.

At the bow the underwater form should represent a gently tapering wedge with edge vertical and cutwater sharp. The angle of the wedge will be determined largely by the length to beam ratio. Whatever this ratio may be, however, the angle of entrance should be made as easy as the conditions will permit, advantage being taken, in most cases of high speed design, of the flat stern to which reference will be made at a later point, and which permits the maximum beam to be carried much farther aft than would otherwise be the case, thus insuring finer angles of entrance than with maximum beam amidships. Regarding the form of sections at the bow, both *U* and *V* shapes are used, but the former may fairly claim the preference, especially as regards wave-making resistance. The lifting effect at the bow is also less pronounced, and there is less disturbance to the trim at high speeds with *U* than with *V* sections. A certain amount of bodily lifting of the boat at the highest speeds with the consequent reduction in wetted surface and in resistance is, of course, to be desired. This may, however, be better determined by a suitable adjustment of the form somewhat farther aft, and the lifting effect thus located will produce but slight change in the trim at operating speeds.

Forms showing a short, vertical cutwater with well rounded forefoot and keel line, gradually sloping thence down to full draft at a point farther aft, cannot be recommended. Length on the water-line is always of importance, and with any such form of cutwater and forefoot there will be a serious loss of effective length of water-line, especially at high speeds or under any condition which may involve a lifting of the bow somewhat above its normal trim. It is of small use to build a boat 40 feet on the water-line if at the highest speeds the bow may rise and shorten the effective length to 35 or even 30 feet. This fault has been noted in some cases of recent so-called "auto-boat" design, and it is one to which designers may well pay special attention.

For the after body the popular torpedo boat model shows for the immersed part of the boat a gradually tapering wedge with edge at the stern, horizontal in line and at the surface of the water. That is, assuming the upper part of the boat cut off by a plane at the water surface, the remaining part would show such a wedge-shaped form, its base joined to the forebody, and with its lower surface sloping easily upward to the horizontal edge at the stern, and lying at the surface of the water. The older form of after body is in general character similar to that of the forebody, but with pronounced *V* or flaring sections near the stern, thus permitting a better run of water to the propeller, and presenting less resistance to propulsion than would result with a duplication of the form at the bow.

Comparing these two forms of stern, the following points may be noted as constituting the chief claims of the torpedo boat form for special consideration.

(1) It permits the greatest beam to be located well aft of amidships, thus insuring finer water-line or entrance angles at the bow.

(2) It places the surface of the boat at the stern in the best possible position to find support from the water pressures in that locality, such upward pressures effectively resisting the tendency to settle at the stern so commonly shown by small boats at high speeds, and which may so seriously disturb their running trim.

(3) The entire absence of deadwood places the propeller still more satisfactorily in the direct run of water under the stern, and thus contributes to its effective operation as an instrument of propulsion.

(4) On the same over-all dimensions it gives more water plane area than the common ship-shaped form, and thus more

stiffness against heeling, more stability, and more safety so far as the latter may depend on these characteristics.

(5) For the same reason as in (4) the part of the boat above water may be made more roomy at the stern, thus adding to the comfort and general serviceability of the boat.

On the other hand the following two points must be set as disadvantages over against the preceding desirable qualities:

(1) The large amount of nearly flat, horizontal surface at the stern tends to render the boat uneasy in a seaway, and may result in severe pounding. It is, in fact, generally agreed that for service in rough weather this form of stern is somewhat inferior to the older or ship-shaped model.

(2) The absence of deadwood places the propeller as it were out in the open, and thus exposed to damage from floating drift or in case of grounding.

Mention may be made at this point of the possibility of so adjusting a stern overhang that the water-line length when the boat is at rest shall be considerably less than when under way. The rating of boats for regatta purposes naturally includes the water-line length as an important factor, and such a form of design may result in the location of a boat in a lower rate than that in which she might belong if measured when running at a high rate of speed. An overhang carrying out the general form of the stern and located just clear of the water when at rest will be brought down by a small change of trim due to slight settling at the stern, and will thus form a part of the effective length of the boat. This is a matter primarily of jockeying, and has no relation to the scientific basis of boat design. The length for rating should in fact be determined on the water-line when running at top speed, and with such method of measurement there would be no further temptation to resort to such methods of gaining an advantage in measurement rating.

Quite aside from the question of rating the form at the stern should be so adjusted with reference to the weight schedule and to

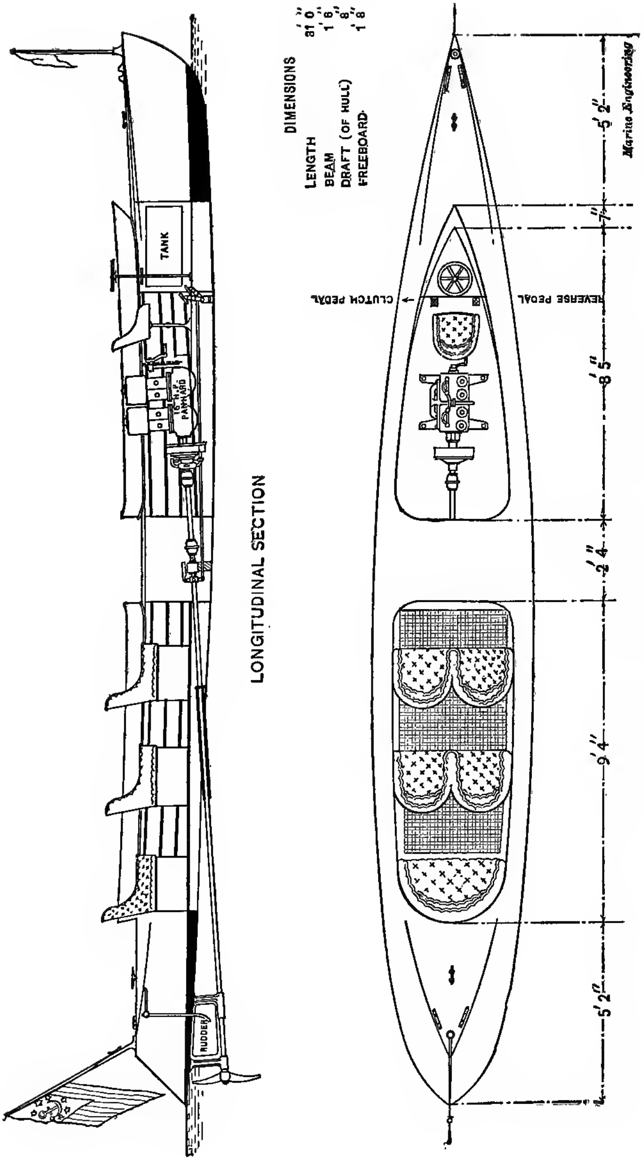

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FIG. 37.—31-FOOT AUTO-BOAT WITH PANHARD ENGINE.

a suitable location of the machinery and other weights, that at top speed the lower knuckle or under surface of the boat at the stern will nicely settle to the surface of the water, and without tendency to sink lower and drag or plow a furrow, as is too frequently the case with sterns of this form when improperly adjusted for trim.

With regard to the midship section, the general form for the older ship model shows usually a rather sharp rise from the keel, approaching in many cases to the so-called peg-top form. As compared with a flatter and more nearly rectangular form of section this form has the effect of increasing the draft for the same total displacement, and of thus improving the seaworthiness of the boat in rough water, or of insuring a suitable immersion of the propeller at the stern without too great a drop of the skeg below the keel line.

For the torpedo boat or flat-stern model the midship section is more nearly flat on the bottom, and is thus more full in form than the typical section for the ship-shaped model.

These various characteristics in either form when combined with a pronounced longitudinal paring away resulting in a distributed leanness or fineness of form, provide the conditions most suitable for the highest speeds, especially with reference to wave-making resistance. As the demands for speed are less pronounced the form will respond by becoming fuller at all points, and especially along longitudinal lines, thus giving more internal capacity and more displacement on the same over-all dimensions and proportions.

Between the full flat torpedo-boat form and the ship model are found various "compromise" forms partaking in varying degrees of the qualities of both. The main purpose of such forms is to retain in good measure the characteristics and qualities of the flat model, and at the same time to provide a form somewhat better adapted to rough-water conditions.

Considerations of space forbid any further discussion of underwater form, and in no case can the preceding be considered as more than a general indication of the lines along which designers are working, especially when high speeds are of primary importance in the schedule of required qualities.

In general the flat or torpedo-boat stern represents the typical form for modern motor boats, and especially for all cases in which high speeds form an important consideration. On the other hand, the older type of stern may often be preferred for lower speeds or for cases which may be influenced by special conditions of the service required, while intermediate between the two, various types of compromise form are to be found, dependent on special conditions of the service or on the fancy of the designer.

ABOVE-WATER FORM.

The form of the boat above the waterline is to be determined by reference to the following four main considerations:

(1) Utility.
(2) Safety.
(3) Appearance.
(4) Air resistance.

The relative importance of these will naturally vary with the details of the case in hand. Where the highest possible speeds are desired the question of air resistance will become of importance, and may lead to a type of form in which all other considerations are sacrificed in varying degrees. It will be convenient to take this extreme type of form as a starting point, and we shall therefore consider first the problem of air resistance and the means which may be taken in order to reduce to a minimum its influence on the speed of the boat.

Because air resistance is comparatively small, especially at low speeds, it should not be assumed that it is by any means negligible. Indeed when the highest attainable speeds are aimed at no item can be neglected, due attention to which might in any way help forward the main purpose in view. Air resistance becomes of the more importance because of the fact of cross and head winds which must be encountered, and the added relative velocity which will exist in the latter case. Thus a fast motor boat going at the rate of 20 miles per hour in still air meets an air resistance due to this speed. A moderate headwind of 10 to 15 miles per hour will raise the relative speed to 30 or 35 miles and will easily increase the air resistance to two or three times its first value. So much the more serious will be a headwind of 20 or 30 miles per hour, raising the relative velocity to 40 or 50 miles and increasing the air resistance four to six fold at the same speed through the water. With such a rapidly increasing fraction of the total power absorbed in overcoming air resistance, it is clear that any such conditions of adverse wind will seriously lower the highest attainable speeds, and that such scaling down will be more pronounced as the above-water form departs farther from the conditions for low air resistance.

As the first principle to be held in mind it may be stated that forms favorable with respect to air resistance should be as nearly as possible smooth and continuous in curvature, and especially with the minimum amount of abrupt change of form or flat head surface. Such features as a standing awning or a projecting pilot house should not be tolerated for a moment if air resistance is to be reduced to the lowest terms. In short, it should be remembered that the upper body of the boat is passing through a fluid (air) no less real than that through which the lower body is passing, and no less capable of occasioning a resistance, even though it is usually much less in amount. It follows that the form most suitable for low air resistance must be similar in general character to that most suitable for low water resistance; or, in other words, that the form of upper body should be not far different from that of lower body. This, of course, is impracticable in full measure, but we may with advantage remember that as the upper body is made to resemble the lower body in general form and character, so will the air resistance be decreased, and by so much less will the attainable speeds be cut down by this cause. It will thus be of interest to note the form of upper body which, in accord with these principles, would insure minimum air resistance.

Such a form would show in general a turtleback type of construction, covered completely over and sloping down to a junction with the under-water body as nearly as possible at the water surface. In side elevation it would show an arched form rising from near the water surface at the bow to a maximum height somewhat forward of amidships and sloping down gradually to the water surface at the stern. Similarly, in transverse section, the form will resemble an arch rising from the water surface at each side to a maximum height amidships, the general proportions of such arch being at the same time adjusted to the general character of the fore-and-aft form. Optical means for enabling the steersman to find his way, as well as general questions of light and ventilation, are, of course, matters which need not be considered in connection with such a form, which is intended only as an ideal toward which actual construction may approach as the need of reducing air resistance becomes of higher importance.

Habitability and general utility with such small boats require an open cockpit as well as some freeboard for safety, while for rough water conditions the forward deck cannot be made to slope down quite to the smooth water line of flotation at the bow. It is of interest to note, however, that the turtleback form, especially forward, has met with favor by many designers, and that in skilled hands it may be treated in such manner as to yield a form not displeasing to the eye, and unquestionably contributing largely to the reduction of air resistance at high speeds.

Turning now to a more general census of the factors which determine the above-water form, they may be specified as follows:

(1) Sheer line and freeboard.

(2) Waterline.

(3) Form of bow.

(4) Form of stern.

(5) Arrangement of cockpit, deck erections, etc.

There is much diversity of practice in connection with the item of sheer. In general, however, the present fashion with motor boat designers seems to lead to less sheer than was formerly in vogue, especially for small craft of 20 feet or thereabouts in length. With racing craft, or boats of the highest attainable speed, the upper line shows often but slight sheer at the rail, and at a distance, taking the rise of the forward deck amidships, the central longitudinal line shows often a slope downward and forward, as in the turtleback type elsewhere referred to. Sheer has its uses in connection with safety and dryness forward, and unquestionably lends a jaunty and pleasing air to boats of moderate size, and with such other proportions and characteristics of form as show them to be intended for moderate speed. On the other hand, the long, slender form of the racer agrees well with the slightly curved rail line and with the forward and downward slope of the central fore-and-aft line, as noted above.

Freeboard as a factor in the above-water form bears important relations to both safety and air resistance, with perhaps more secondary relations to general utility and appearance. Insufficient freeboard may give rise to two dangers—the shipping of water in moderately rough weather and a reduced range of stability. Each of these may involve some element of danger for the boat, and having due regard to safety in these respects, a reasonable freeboard should be provided. What is reasonable in any given case must be determined by the designer in view of all circumstances of the case, and for the purposes of the present discussion it will be sufficient to simply note the principle that in general increase of freeboard up to some value considerably beyond the usual proportions will make for increased stability range, and for added safety in this particular. Increased freeboard means however, increased air resistance, especially in a headwind; and here, as at all other points, we meet the necessity of compromise and adjustment between mutually conflicting requirements.

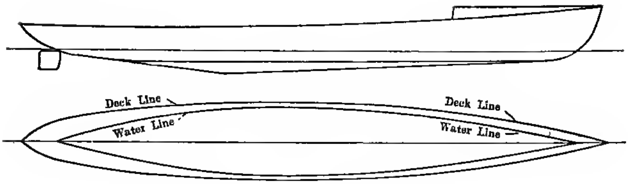
Regarding the waterline or plan view, the form and proportions of this feature will depend primarily on the under-water body, as considered in the preceding chapter, and this item will require no further consideration at the present point.

Regarding the form of the bow, some designers are disposed to flare out the sections from the water surface upward at and near the bow, thus rapidly increasing the bearing as the bow descends into the water or dives into a wave. This will have the effect of reducing somewhat the extent of pitching in a head sea, and may thus contribute to safety and comfort. As a rule, however, having in view the average weather in which such boats are expected to be used, most designers are content with a nearly vertical side at and near the bow, depending on the freeboard and other general proportions to give the needful steadiness relative to pitching, and the general safety relative to the action of the waves.

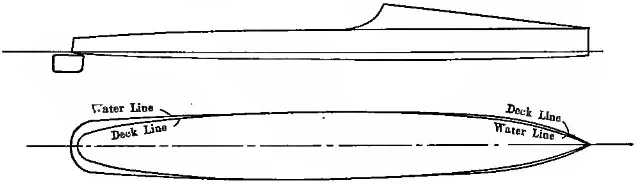
The form of the cutwater has been noted in the preceding chapter. General practice leans toward a cutwater raking somewhat forward and with a rounded curve under the forefoot. The tendency of these characteristics in excess will be to shorten the waterline length when running at high speeds, as already noted. So far as this consideration is concerned, therefore, the forward rake should be very nearly suppressed and the round under the forefoot should be kept at least under water when at full speed.

Coming next to the stern, we meet perhaps the most difficult of all features of boat design, especially with reference to considerations of general appearance. The character of the torpedo-boat stern has been already referred to in connection with the discussion of the under-water body. There is no question of the difficulty of the problem which this stern has presented to designers with respect to the combination of the typical form below water with pleasing form characteristics above water. In the earliest sterns of this type the above-water form was usually some close approximation to the older and familiar round or raking stern, joined by an abrupt knuckle to the flat floor of the under-water body. These combinations were rarely graceful or pleasing, representing as they did the attempted combination of two entirely distinct types of form, neither part properly adapted to the other. In later and more satisfactory forms the old and conventional stern has been left aside and new above-water forms have been developed in conformity with the general conditions of boat design and with the type of under-water body with which they are to be joined. In certain varieties of this type the member corresponding most nearly to a sternpost is raked or curved forward, while the water-plane and horizontal sections cut by all parallel planes are brought to a point either sharp or somewhat rounded. The chief disadvantage of this variety is perhaps that in its more narrowly pointed extreme it is somewhat less well adapted to a wide and roomy stern cockpit, or in any event such pit cannot extend quite as far aft as in forms which are broadly rounded or flat across the after extremity. Such rounded or flat varieties, with more or less pronounced tumble home, and in elevation showing a forward rake to the after boundary line, represent still other solutions of the same general problem; and all varieties here noted, with intermediate gradations, are to be found in the practice of the day. Reference may also be made to the cuts accompanying the preceding and present chapters for illustrations of these forms of above-water body.

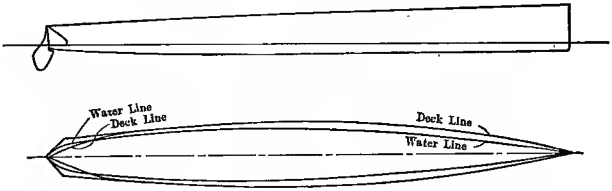
Comparing for a moment the torpedo-boat stern with the older or ship form with deadwood and fine waterlines aft, it will be seen that the natural widening of the above-water body which the torpedo-boat stern permits gives usually more width and roominess on about the same proportions, and is thus favorable to general utility and comfort. With the rounded or flattened after extremity this width is especially pronounced,



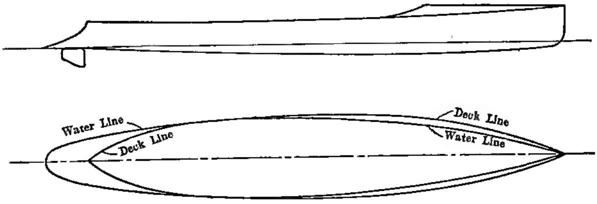
Length 81 Feet Speed 22 Miles



Length 40 Feet Speed 22 Knots
Speed 25.9 Knots ?



Length 40 Feet Speed 20 Miles



Length 30 Feet Speed 19 Miles *Marine Engineering*

FIG. 38.

and is the feature especially commending such variety of form for various classes of boats. Naturally, however, excessive width and roominess must go with moderate speed, and *vice versa* the highest speeds can be expected only with such forms as involve some sacrifice of width and general carrying capacity. Utility, further, is a quality which must be interpreted in accordance with the nature of the case, and it is not until it is thus interpreted and expressed in engineering terms that it becomes a matter capable of direct study and definite determination.

Again, as regards appearance, it must be remembered that this is largely a matter of taste and convention, and taste is largely a matter of education. When the torpedo-boat stern was first introduced it was generally considered as decidedly ugly and lacking in all those qualities of grace and beauty which may be embodied in the older and conventional form. To-day forms of torpedo-boat stern are worked out in such a manner as to appear pleasing to the eye and generally satisfying to our sense of the beautiful. This is due to two chief causes: (1) Since its first introduction we have become accustomed to the general characteristics of this form of stern and to its peculiarities, as distinguished from the older form, and have thus become educated in the toleration and acceptance of features which, with our conventions and ideas of fifteen years ago, seemed crude and displeasing. (2) The problem has received a vast deal of attention and study on the part of naval architects and designers, and forms and proportions have been evolved which are unquestionably more pleasing than those through which this form of stern first made its appearance as a factor in small boat design.

Again, it must be accepted as a principle of all such classes of design that in a boat intended for the highest speed, considerations of utility and especially of appearance must be made subordinate to those qualities having primary relation to the requirement of speed. It must not be concluded, however, that a fast boat is necessarily ugly. Within the limitations imposed by the requirement of high speed, the skilful designer will be able to combine his elements in such manner as to be at least not displeasing to the eye while at the same time fulfilling the technical requirements for maximum speed.

So far as considerations of safety are concerned, the torpedo-boat stern suffers somewhat by comparison with the older form as regards ease of riding through a seaway. The flat under-water after body may result in a tendency to pound in a choppy sea, while backing into a strong head sea is of course well nigh out of the question. On the other hand, the increase in average beam at the waterline, which is a pronounced feature of the flat stern, makes for stiffness and large stability for small angles of heel, though the range of stability may be no more or even less than for the older form.

So far as air resistance is concerned there is but little to choose between the two fundamental types of stern, though of all varieties in actual use the typical form with forward rake and with sharp or moderately rounded after extremity will undoubtedly show most favorably in this respect.

Because the flat or torpedo-boat stern has been treated thus in detail it must not be considered that it is the only form of stern used for small craft of the motor boat class. The old and conventional stern with deadwood is still met with, and in particular for boats intended for cruising purposes, and where moderately heavy weather may be expected; or, on the other hand, in boats intended for very shallow water, or when the fullest measure of protection to the propeller is desired.

Again, there are various intermediate types coming under the head of compromise sterns, and intended to retain the favorable qualities of the flat stern with respect to resistance and propulsion and at the same time to avoid some measure of the uneasiness of the full flat stern when riding in heavy weather. Such forms have usually no deadwood and show an under-water body sloping upward toward the stern, but with sections somewhat rounded or eased off at the waterline, thus avoiding the full flat characteristic of the typical torpedo-boat stern. The above-water body may be worked out in various forms according as the design leans more nearly toward the old conventional form or toward the flat torpedo-boat model. There is probably little to be gained by the use of such compromise forms beyond some slight measure of better adaptation to rough water conditions. For smooth water, or such conditions of water and weather as may be fairly considered typical for the motor boat class, the flat or full torpedo-boat stern may be accepted as generally preferable from all points of view.

Regarding the item of cockpits, trunk cabins and deck erections of all kinds, little can be said of value in a general discussion such as the present. These features pertain chiefly to utility, and their character must be determined in connection with the special needs of the case. The influence of deck erections in augmenting air resistance has been already referred to, and for high speeds so serious will this become that with small boats these features of comfort and utility must be sacrificed if the highest attainable speeds are contemplated.

The general consideration of safety has been mentioned in connection with several features of the above-water form. Some further points may be noted as follows:

It is clear that the above-water form which is ideal for smooth water conditions will be far from permissible in rough water, or even in the average weather conditions with which such boats are expected to be able to safely contend. Especially will this be true for high speed requirements, and it follows that the above-water form as related to speed in particular, and all other requirements in general, must be determined with reference to average weather conditions. In particular, will such requirement lead to modification in the ideal turtle back form of forebody. In average weather conditions a forward deck sloping down nearly to the waterline at the bow, as determined by smooth water trim, would result in the boat's running most of the time with her nose under water, and in heavy weather such a form would be quite out of the question, at least for any speed above the very slowest. While, therefore, a turtle back form is favorable to reduced air resistance, and to the rapid shedding of a wave should it break over the bow, yet its height nevertheless must be such as to lift it above the reach of the ordinary small waves, and beyond the likelihood of nosing deeply into the water under such weather conditions as are liable to be encountered. The same considerations will lead to a general increase of freeboard over that suitable for smooth water, and to other modifications of minor character intended to render the boat safe and comfortable under average weather conditions.

THE DESIGN OF FORM.

The design of a motor boat as a whole is readily seen to divide itself into the two main problems of the design of form and the design of structure. In the present chapter we shall consider the design of form. In the preceding chapter we have discussed the principal characteristics of form and their relations with the various qualities of the boat, such as speed, safety, carrying capacity, etc. We have now to consider methods for determining in a regular and systematic manner such general form characteristics as may be desired, and for the representation of such form in manner best suited to the needs of the practical builder.

Before taking up the discussion of actual designing methods, however, brief reference must be made to certain so-called form or fineness coefficients.

Let the length of the boat on the water line be denoted by L, the breadth by B and the draft by H. Then the product B × H will be the area of a rectangle which will just contain the immersed midship section. Let M be the area of the actual section.

Then the ratio $M \div BH$ is called the *midship section coefficient* and represents the fraction of the total area which the actual section contains.

Likewise the product $L \times B$ will be the area of a rectangle which would just contain the water plane or horizontal section at the water line. Let A be the area of the actual water plane. Then the ratio $A \div LB$ is called the *water plane coefficient* and represents the fraction of the total rectangle which the actual water plane contains.

Again the product $L \times B \times H$ will be the volume of a box which would just contain the under water form. Let V be the actual volume of the under water body. Then the ratio $V \div LBH$ is called the *block coefficient,* and evidently represents the fraction of the total box volume which the actual boat form contains.

Again the product $L \times M$ will be the volume of a solid of section constant and equal to M, and of length equal to that of the boat. Then the ratio $V \div LM$ is called the *prismatic coefficient,* and represents the fraction of this total volume which the actual boat form contains.

It is readily seen that the indications of the midship section coefficient refer solely to the form of this section, and give an estimate of its fullness compared with a rectangle as the standard. The indications of the water plane coefficient, similarly, refer solely to the form of the load water line, and give an estimate of its fullness compared with a rectangle as the standard. The indications of the block coefficient, on the other hand, refer to volume, and give an estimate of the fullness of underwater body compared with a rectangular block or prism as the standard. Similarly the indications of the prismatic coefficient refer to volume and give an estimate of the fullness of underwater body compared with a body having length L and a constant cross section M. A little thought will also show that this coefficient refers solely to what may be termed fore and aft fining.

Suppose again the areas of a series of sections taken to the load water line, and let them be denoted by M_0, M_1, M_2, etc. Let these be plotted on an axis of length each at its own station. The result will be a curve similar to that of Fig. 39, and called a curve of sections. The maximum height of the curve, *B D*, represents, of course, the area of the midship section, or M, as noted above. The distance *A C* represents likewise the length L. Then the product L M is represented by the area of the rectangle *A C F E*. The area of the curve *A B C D A* in a similar manner represents the volume of the actual boat form, which we have denoted by V.

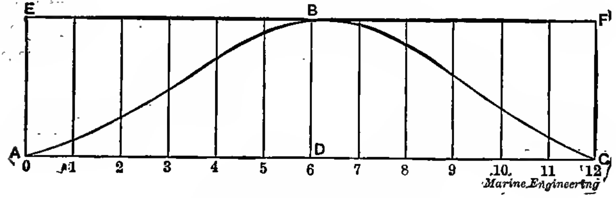


FIG. 39. CURVE OF SECTIONS.

The complete proof of this last statement would require an application of the integral calculus, which would take us outside our purpose in the present series of articles. The fact may be seen in a semi-mathematical manner as follows:

It is clear that the volume of the boat will be measured by the length multiplied by the mean or average cross sectional area. It is likewise clear that the area *A B C D A* will be measured by the length *A C* multiplied by the average vertical dimension or ordinate. But the length *A C* represents the length of the boat, and the ordinates of the curve represent the cross sectional areas. Hence the product of the length *A C* by the average ordinate will be proportional to the product of the length of the boat by the average area of section. Hence the area of the curve will be proportional to the volume of the boat, V. It is then clear that the ratio V ÷ L M will be the same as the ratio between the two areas *A B C D A* ÷ *A C F E*. It follows that the prismatic coefficient is the area coefficient of the curve of sections, *A B C*, and shows the fullness of the area *A B C D A* compared with the rectangle *A C F E* as standard.

The usual range of value in the midship section coefficient is from .65 or .70 in the peg-top form of section as in Fig. 40, to .90 or above in the flat floor and sharp bilge form as in Fig. 41.

The usual range of values in the water plane coefficient is from .65 or .70 in very fine forms of the old or ship type with deadwood, through .75 or .80 for fine forms with torpedo boat or flat stern, and to .85 and upward for very full forms.

The usual range of value in the block coefficient is from about .40 or .45 for fine forms to .50 or .60 for moderate and to .70 for full forms. Extreme forms for high speed may have a coefficient as low as .35, and the whole range of boats for pleasure and high to moderate speed may be expected to show values of the block coefficient from this figure up to about .50.

The usual range of value in the prismatic coefficient is from about .6 for very fine high speed forms to .70 or .75 for moderate speeds, and to .80 or .85 for low speed and large carrying capacity.

We may turn now to the various plans and lines by means of which the form of a boat may be represented on the drawing board.

If we suppose a series of planes passed parallel to the surface of the water they will cut out from the form of the boat a series of lines known as water lines and having the general form shown in Fig. 36 (lower plan). Since the two sides of the boat are the same it is customary to show the lines for only one side. Hence the plan showing such lines is known as the *half breadth plan.*

If, again, we suppose the form cut by a series of planes vertical and transverse, or perpendicular to the base line, they will cut from the surface of the boat a series of lines known as *sections* and having the general form shown in Figs. 36, 34 (small plan). Here also, since it is unnecessary to show more than one side of the boat, it is customary to show on one side the sections of the fore body and on the other that of the after body. Such a plan is known as a *body plan*.

The plan shown in Fig. 36 (upper plan), and which gives the side elevation of the form, is known as the *sheer plan*. If the boat is cut by a series of fore and aft vertical planes, the lines cut out from the surface are shown in such a plan, and are called *bow and buttock lines*. Referring again to Fig. 34, if the form of the boat is cut by a series of oblique planes running fore and aft and lying as nearly as possible perpendicular to the surface at various depths, they will cut from the surface a series of lines which may be shown, each in its own plane. Such planes, indicated by *A, B, C, D, E,* Fig. 34, are known as diagonals, and the resulting lines are shown in developed or true form in the upper plan on the right. The chief use of such lines is in fairing up the other plans so as to insure a smooth and continuous form, especially near the bow and stern, where the indications of the other plans are sometimes less definite or exact.

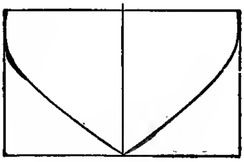


FIG. 40.

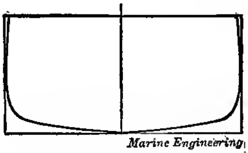


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FIG. 41.

Referring now to Figs. 36 and 34, the water lines may be fined away sharply fore and aft, beginning from the midship section; or they may carry nearly the full width for some little distance fore and aft and then fall away more abruptly to the pointed extremities. Such forms of water line are more specially typical of the ship form with deadwood. On the other hand, with the torpedo boat stern the typical form of water plane is shown in Fig. 36. It is sharp pointed at the bow, and gradually widens, gaining its greatest width frequently at some little distance aft of the mid length, and then rounding off to the stern as shown.

With the ship form of under water body the fineness of water plane will increase as the required speed is higher, while as speed requirements are less exacting and more carrying capacity is required, the water lines will become fuller in form, and the bow and stern will become less sharply pointed. With very full boats of this form the after body should preferably be somewhat finer than the fore body, in order to diminish eddy resistance at the stern and facilitate the flow of water to the propeller. With the torpedo boat type of stern the form of the water lines in the after body shows but slight variation, with general fullness of form. With the fore body, however, the general fineness of water line is greater, and the angle of entrance is less as speed requirements are greater.

Turning now to the body plan, the sections may at one extreme be nearly rectangular, or at the other extreme more nearly triangular, or even hollowed in as near the stern in ship-formed bodies. The general character of the transverse sections in any one boat is to a considerable extent determined by the form of the principal or midship section, which thus becomes a general index to the form so far as it may be determined by the sections. The usual form of midship section for motor boats shows a moderate to well marked rise of floor, as in Figs. 36 and 34, with a well-rounded bilge and side, often sloping outward slightly at the water line and rising to the vertical near the rail. Within this general type the variations in form of midship section are determined not so much by requirements of speed as by minor or secondary considerations. Thus, if especially shallow draft is desired the midship section will have a rather flat floor, with relatively less rounding off on the bilge, and consequently a high midship section coefficient. On the other hand, if deep draft on moderate displacement is desired, the form of midship section will tend toward the "peg-top" type, that is, with sharp rise of floor and well rounded bilge. In general, however, the flat, shallow section is not the most favorable to seaworthiness, nor is the relatively sharp bilge of Fig. 41 as favorable to low resistance as the more rounded form of Fig. 34. For the best combination of speed, seaworthiness and generally desirable qualities, both extremes are to be avoided, and the prevailing form of midship section in such boats is usually found somewhat as indicated in Figs. 36 and 34.

With the torpedo boat type of stern the after sections become shallow as the stern is approached, and relatively full compared with the surrounding rectangle. This, however, does not necessarily denote fullness of form as determined by cross sectional area compared with that of the midship section. It simply means, as already explained, that the fining away is vertical rather than horizontal.

Toward the bow, with both forms of stern, the sections approach the V or U shape, according to the designer's choice. The latter are presumably somewhat more favorable with regard to resistance, while the former, especially above the load water line, will tend to give lifting power to the bow in a seaway, and hence to reduce the pitching and amount of water shipped when running into a head sea.

Having thus discussed the various geometrical plans and projections and coefficients of form, we may undertake consideration of the problem of actual design. It should first be noted that but rarely is such a design absolutely new and without a more or less direct dependence on previous forms. The accumulation of such forms in any drawing office furnishes a series of starting points from which, by slight modifications in various ways, a vast number of derivative forms may be produced, and in this manner the conditions for new problems may be readily fulfilled. Such modifications may be of two kinds: those involving a change in the proportions of length, beam and draft or depth, and those involving a change in some or all of the fineness coefficients as discussed above.

In the simplest possible case it may result that the proportions and form coefficients may all be considered satisfactory. The only change in such case is one of dimension or scale. No new design is therefore required, and the conditions may be realized by a direct increase or decrease of all dimensions in the same ratio. In such case it is not as a rule necessary to make any change on the drawing board or to redraw the lines to the new scale. All such changes may be made when the boat is laid down in the boat shed, and in general manner as will be described at a later point.

A more common case arises in connection with the acceptance of the various coefficients of form, but with requirements which call for some change in the proportions of the three principal dimensions L, B, and H. Thus let us suppose that a given set of lines relates to a boat 24 feet long, 5 feet beam, and 2 feet draft. It is desired to use the same characteristics of form for a boat 30 feet long, 5 feet 3 inches beam, and 2 feet 3 inches draft. The various proportions between the new and old would, therefore, be as follows:

$$\begin{array}{ll} \text{Length ratio} & = 30 \div 24 = 1.25 \\ \text{Beam ratio} & = 63 \div 60 = 1.05 \\ \text{Draft ratio} & = 27 \div 24 = 1.125 \end{array}$$

This means simply that the new boat is to be 25 percent longer than the old, 5 percent wider and 12.5 percent deeper. Here again no work whatever need be done on the drawing board, as the changes required may all be made when laying the form down full size. The general method of procedure with these ends in view may be outlined as follows:

The first step will be to obtain the new water line or half breadth plan. To this end we note that the intervals between the sections must be increased in the same ratio as the length as a whole. Thus suppose in the original drawing that 12 sections were employed, giving a spacing of 2 feet between each, then the new spacing will be similarly 30 ÷ 12 or 2.5 feet. The ordinates at each end of these stations must then be scaled from the original lines or taken from the so-called table of "offsets" and then multiplied by the breadth ratio 1.05. This will give the lengths of ordinate to be set off at the new stations, and the resulting lines will constitute the new half breadth plan as desired. This operation for a single water line is indicated in Fig. 42. The new length of 30 feet may then be divided into any frame spacing as desired and the locations of the frames drawn in. To determine the form of section at these stations, and hence the actual form of the frames, the vertical spacing of the ordinates must be increased in the ratio of the drafts, or 1.125. If therefore the old spacing was 3 inches the new must be 3 × 1.125 or 3.375. Horizontal lines laid down to this spacing may then be taken as the basis of the body plan, and the ordinates, taken from the new half breadth plan, and laid off on these lines, will give correctly the forms of the sections or frames as desired.

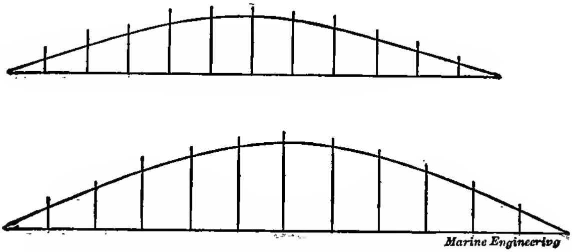

FIG. 42. EXPANSION OF HALF-BREADTH PLAN.

In laying down a new design by this method, and after the form has been determined as above, it may be desired, as a matter of record, to lay down a new set of water planes in the body plan, spaced at some even interval, such as 3 inches. The ordinates taken from such a set of planes may then be made a matter of record in a table of offsets. For such purpose it will be well to distinguish the new set of planes by a different color or by some other arbitrary distinction in order to avoid confusion.

In any such problem of design many practical points will arise which cannot be completely treated in the present brief account of general principles. By the intelligent application of such principles, however, and in the general manner indicated, it will be found a simple matter to lay down a new set of lines having the same characteristics as the initial or type form, but with the proportions of L, B, and H modified in any manner desired. It may sometimes happen that one or more of those ratios may remain the same in the new as in the old form. Thus it may be desired to retain the same ratio of L to B or B to H, or indeed to retain all ratios the same, in which case the change becomes one of size alone, already discussed as the first and most simple case. Again in case the new dimensions are smaller than the old, or some smaller and some larger, the same general principles apply. In short, for all cases, no matter how special, where the form coefficients are to remain the same and a new form is to be derived with new dimensions and new proportions of L, B and H, the same general procedure will serve to determine all features of the new form as may be desired.

We come next to the more general and more difficult problem of including changes in the form coefficients as well as in the proportions of L, B and H. Thus it may be desired to change the character of the midship section, to fill in here or fine away there, and so in various ways to modify the characteristics of the original form. In such case it becomes a problem for the drawing board, at least to a first fairing out, before proceeding to lay down the form full size on the floor. The character and extent of such modifications may be judged by three forms of test as follows:

(1) The satisfaction of the eye as a judge of form or proportion;
(2) The satisfaction of the judgment regarding certain desired or suitable values of the form coefficients;
(3) The provision of some needed dimension or space for reasons of structure or arrangement.

If the extent of such changes is not great the original lines, or more especially the body plan, may be taken as a foundation, and the changes lightly sketched in free-hand, fining out or filling in and changing in various ways, until, as judged by one test or another, the desired form is approximately determined. If the body plan has been taken as the base for such changes, then the result on the fairness of form must next be determined by reference to the water lines, bow and buttock lines or diagonals. It will thus be found that, in order to run in smooth or fair lines on the second plan, slight changes must be made back in the sections of the body plan, still retaining of course the fairness of the latter. In this manner it will be necessary to make slight changes back and forth, the changes in one plan being tested by the results in another, until finally both or all plans are as nearly fair as may be determined on the reduced scale used on the drawing board. In making any such series of changes it must be remembered in particular that with a fair form as a foundation a change in any one section, for instance, will necessitate a change in all the water lines in the neighborhood, and hence in order to retain the latter fair, a change in all the sections for some little way on either side of the one first affected.

The operation of thus changing back and forth between two plans, or fairing up, as it is termed, involves many minor points of detail which cannot be here considered, and regarding which experience will be the best teacher. The final purpose in any such design is the determination of a smooth and fair form with the general proportions and form coefficients selected as suitable for the case in hand, and if a form nearly fulfilling the desired conditions can be found as a start, the general procedure above outlined will serve to develop the desired changes.

We may now advance to the general and still more difficult problem of a design new from the start. It is clear that such a design cannot spring from nothing. There must be some form of initial data giving such conditions or characteristics as may serve to make possible a start toward a solution. Such initial data must then be either furnished by the conditions of the problem, or must be assumed to an extent sufficient to make the problem definite and its solution practicable. The features to be thus chosen or assumed may vary somewhat with the choice of the designer. Here as in all cases of engineering design there is no one road leading from the data to the design. There are many routes which will lead from the same starting point to the goal, and the particular route to be taken thus becomes largely a matter of individual choice. For most cases the following may be recommended as a safe and convenient procedure:

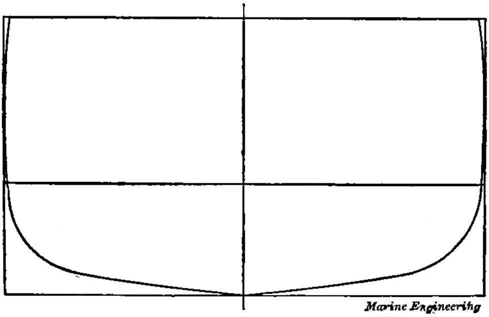
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FIG. 43. FORM OF MIDSHIP SECTION.

The principal dimensions, length, beam, depth, and draft are supposed to be given. The first actual step may be to lay out the form of the midship section. The beam and depth of boat amidships will give the rectangle surrounding such section, and within such rectangle a form of section may be sketched in, having in view the influence of this feature on the design as a whole, and selecting such type as may seem best adapted to the purposes in view. This step is indicated by Fig. 43.

Having thus selected the form of midship section, the next step may be to run in a sheer line and keel as shown by Fig. 44, thus fixing the general contour of the boat in longitudinal section. At this stage the form of stern must be selected, whether with or without deadwood, ship form or torpedo boat form, and the keel line adjusted accordingly. The next step may be to run in a load water line *A B C*, Fig. 45, a rail line *D E C* and a curve of sectional areas *A B C*, Fig. 39. The forms of the load water line and of the curve of sections may be judged either by the eye or by reference to their form coefficients as previously discussed. It will be noted further that the curve of sections is intended to represent the areas of sections up to the load water plane; or in other words that it is intended to refer only to the part of the form lying below the load water line. The maximum ordinate of this curve, *B D*, Fig. 39, must represent therefore the area of the midship section up to the load water line, and the curve of sections should be laid down in a rectangle *A E F C*, of which the length *A C* represents to some convenient scale the length of boat on the water line, and the breadth *A E* the area of midship

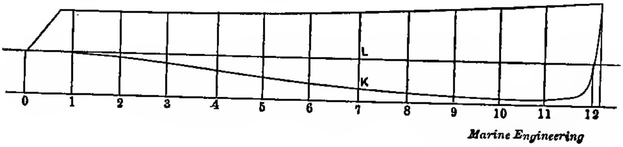

FIG. 44. BODY PROFILE OF MOTOR BOAT WITH TORPEDO STERN.

section up to load water line, laid off to any arbitrary and convenient scale. To the same scale therefore any other ordinate, as number 7, will represent the area of the corresponding section of the under water body of the boat.

These three features (deck or rail line, load water line and curve of sections) cannot however be selected independently, but must be taken each with reference to the others, and with reference to its general influence on the design as a whole. If the form has the ship type of stern with deadwood, the curve of sections has the characteristics of a mean or average water line. Hence in such case the deck line will be the fullest in form, the load water line will be next and the curve of sections will be fined away the most. With the torpedo boat stern these same general relations will usually hold for the fore body, while for the after body the form of load water line and deck line will be quite unlike that of the curve of sections. In any case the load water line and rail line must agree at the midship section with the form already determined for this section; but aside from these two points and the ends, which are determined by the sheer plan, these various lines are quite undetermined and must be laid in with the best judgment available. It is very sure, however, that the lines thus taken will not satisfactorily agree, and that all will require more or less adjustment and accommodation to bring them into satisfactory harmony as features of the design. To determine these points the design must be still further developed, and to this end we proceed as follows:

Take any section, such as number 7, and determine by reference to the curve of sections the area which is called for. Then multiply the depth of section taken from the sheer plan, *K L*, Fig. 44, by the half breadth taken from the load water line, *K L*, Fig. 45. The product will be the area of a rectangle which would just contain the half section in question. Then divide half the area taken from the curve of sections by the area of this rectangle and the quotient will give the fineness coefficient for this section and will show to what extent a rectangle *A B C D,* Fig. 46, with the given depth and breadth must be fined away to give a half-section with area as required. A little experience will enable one to make a close estimate of the shape, knowing the coefficient to be realized. Thus if the value of the coefficient is .72 it shows that *A B C E* must be slightly less than three-quarters of *A B C D,* and a little experience will make it possible to sketch in a form of section nearly fulfilling these conditions. In any case a few trials checked by planimeter will serve to bring the area to the value desired within a satisfactory limit of accuracy. In thus sketching in the form of section, reference must be made to the midship or principal section, and to the general form of section to be held in view, and also to the point *F* determined by the rail line, so that the entire section contour *A E C F* may be run in smooth and fair. In the same general manner the other sections may be run in, care being taken to make the transition in form from one to another not too abrupt, so that the general transition from the midship section fore and aft may be gradual and smooth. For this reason it is also well to start from the midship section, running in number 7, for example, quite similar in form to number 6, the midship section, and only modifying it as may be required by the slight change in area and general dimensions. Next, number 8 is run in with but slight change from number 7, but probably with a growing departure from number 6, and so on to the bow. In the same general manner the after body is determined,

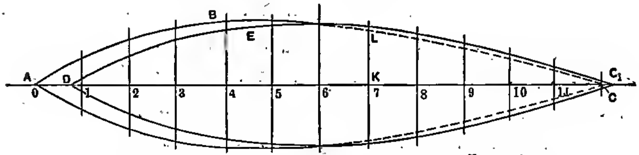

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FIG. 45. WATER LINE AND DECK LINE OF MOTOR BOAT.

both above water and below. In case at any section the various lines as assumed do not agree in such way as to make the form practicable, the fact will be shown by an extreme value of the section coefficient at this point. Thus it might readily result, with the various lines as assumed, that a given section might needs be nearly or quite rectangular in form at one extreme, or triangular or less at the other. In such case the form of the assumed elements must be so adjusted as to give sections throughout having the general character of form desired.

In some cases it may be desired to keep the rail line forward especially full for room on the forward deck, or to give bearing forward when pitching into a head sea. This may be realized by introducing a reverse curve into the forward sections above the load water line, as shown in Fig. 47. In this manner, without increase of under-water body and with relatively fine under-water lines, the desired features may be realized.

When the sections have thus been all sketched in fore and aft, the result will be a set of lines conforming closely to all the conditions thus far imposed; that is, curve of sections, load water line and rail line. It is very sure, however, that a boat built to such lines would not show a smooth and fair surface, but would develop humps and hollows, flat spots and irregularities in a degree wholly surprising to one not familiar with such matters. The next step must, therefore, be the development of a smooth and continuous form, without at the same time sacrificing the conditions already realized as above. The first step in such further program may well be the determination of a series of water lines at from 3 to 6 inches interval, the first being taken perhaps at about mid-draft, and the others, above and below, being run in after such fairing up as the mid-draft line may suggest. The latter, when run in, will probably be found unfair, and will indicate needed modifications in the sections. The same general series of adjustments are then to be carried out as referred to at an earlier point, in connection with the operation of fairing up after making a slight change in a given form. In the same manner other water lines may be run in and faired up, until finally the two sets of lines, water lines and sections, are as nearly fair as may be readily effected with the reduced scale used on the drawing board.

In fairing up the form about the bow and stern, much help may be derived from bow and buttock lines, or from diagonals, as previously explained. The especial advantages of diagonals are as follows: (1.) They often lie approximately in the line of strakes of planking, and thus showing how such strakes will be bent, and furnish a test of fairness along these lines. (2.) The intersections of the diagonal cutting planes with the surface are usually not far from perpendicular, and the points in question are thus located more definitely than by the oblique intersections of bow and buttock lines with parts of the surface nearly vertical, or by water planes with parts of the surface nearly horizontal.

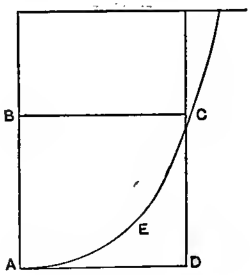

FIG. 46.

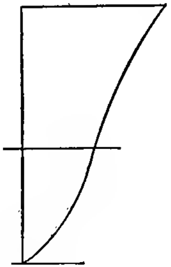

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FIG. 47.

The method of developing a new design thus outlined is more especially adapted to cases in which the qualities to be attained may be satisfactorily interpreted in terms of form coefficients and the general characteristics of the curve of sections. In cases where the judgment regarding the coefficient and form of the water line and of the curve of sections may be less certain, or where the designer may prefer to proceed more directly to the determination of form, the same ultimate end may be reached by selecting first a midship section, as before, and then with pencil sketching in lightly the various sections, those of the fore body on one side and those of the after body on the other. Some guidance may be obtained by looking at a body plan with characteristics somewhat similar to those desired, and distributing the sections in a generally similar manner. By working from the midship section each way, and carefully noting the relation of one section to the next, a form may be developed which will be not far from fair, and which will possess the general features desired so far as they may be determined by reference to the sections. The fairness and continuity both of surface and of volume must then be tested by laying down from the sections a set of water lines and a curve of section areas. These will presumably reveal irregularities in the surface form, and in the distribution of volume. With such indications in hand, the sections may then be modified and faired up by means of water lines, bow and buttock lines and diagonals, and in the same general manner as before described. The resulting coefficients of load water line and of curve of section areas may then be determined, and the values applied as a test or basis of judgment regarding the general character of the form thus developed.

The method first discussed involves the selection of certain features and conditions which the form is to fulfil, and as expressed by the form coefficients and the curve of sections, and then determining a form which shall realize these requirements as nearly as may be finally decided desirable. The second method involves the determination of a form direct from the midship section and without other guide than the eye, and then the testing of this form by reference to its coefficients and curve of sections, until the result shall finally be accepted as satisfactory for the case in hand.

In earlier years the forms of boats were commonly determined by working out a model in wood, and to such reduced scale as might be convenient. This method has the advantage of permitting eye judgment of the solid form, and this is always more satisfactory than judgment in the flat, as on the drawing board. It has the disadvantage that the form must be developed almost wholly by eye judgment, and without initial help from the various form coefficients; also, should the form be made too fine at any point, the error is not readily corrected. On paper, lines may be run in and rubbed out, and the form may be modified in any manner desired, without prejudice to the completion of the problem along any line which may be finally chosen. It is readily seen that with a wood model there is very much less freedom of adjustment and change in this manner, and if patching is to be avoided, great care must be exercised in approaching the final condition, lest a spot undesirably lean may be produced.

If, however, it should be decided to develop the form of the boat by means of a model, such method should be considered only as a first step to the determination of the half-breadth and body plans on the drawing board, and from the latter the coefficients and geometrical characteristics of the form may be determined as previously described. The ordinates, or measurements for laying down these plans, may readily be taken off by calipering, especially if the model is made with lifts as explained below. The form thus produced direct from the model may then be judged by means of these coefficients, especially with reference to the relation between draft, displacement and carrying capacity.

On the other hand, when the form is produced on the drawing board, especially if it contains features of novelty, it may be recommended to make a model before laying the boat down full size and proceeding with the construction. This operation is the inverse of determining the lines from the model. The operation of cutting a model to represent a set of lines is one requiring some considerable skill, and involving many practical details. Within the present limits we may note briefly the following points:

Two general methods of procedure are open:

(1.) A solid block may be glued up, and then pared down as tested by concave moulds cut out to fit the form of the sections, and applied to the model at the corresponding stations. In this manner the block is reduced to the desired form at a series of regularly spaced stations. The intermediate parts are then brought down, and the whole faired up.

(2.) A series of "lifts," or boards of thickness to represent the space between the water lines, is prepared, and the water lines laid out one on each. The lifts are then cut out, each to its own form, and these are then pegged together or glued up, as may be preferred. The corners are then brought down so that the form is smooth and continuous and with water lines as determined. The indications of such a model will often suggest slight changes in the form, and this may be done on the drawing board and followed up on the model, until between the two the resulting form seems to satisfy the judgment taken from all possible points of view.

However the model may be derived from the lines, it may be recommended to always lay up the block out of "lifts" in the manner suggested for the second mode of procedure, and to color the glue with black. This will give on the model definite fine lines in black representing the water lines and aiding the judgment somewhat with regard to the form of the boat along these lines.

In fixing upon the various preliminary characteristics of the design, both draft and total depth will present themselves for consideration. The important question may then arise as to what assurance we may have that when built the boat will come to the draft designed. Definite assurance on this point can be acquired only by elaborate calculations and estimates regarding the weights of boat machinery and equipment. In the absence of such estimates it may be safely assumed, if the general proportions and character of construction are in accord with common practice, and if the boat is powered within reasonable limits, that there will be left over a certain margin of carrying capacity before bringing the boat down to her designed draft. Such margin may then be utilized for passengers, etc., and should provide for all ordinary requirements with a boat of this character. It is not to be expected, of course, that any boat will naturally or necessarily run at just the designed draft. With small boats, in particular, there is often much variation according to the load carried, and so long as the freeboard remains sufficient for safety, the fundamental purposes of the boat may be considered satisfactorily fulfilled.

With definite knowledge regarding the weights of boat and machinery, acquired either from actual data or from computation, the carrying capacity at any specified draft may, of course, be accurately found by subtracting the total weight of boat, machinery and equipment from the displacement as given by the immersed volume up to the water line in question.

In this discussion of the more important points which enter into the problem of boat design, many details have been necessarily omitted or only briefly considered. The primary purposes have been to aid those who already have some acquaintance with such matters, in using their judgment and experience to the best advantage, and to give to those less familiar with the matter such general directions as may enable them to undertake the study of the problem in the way in which they will be the best able to acquire self-confidence, and thus to develop such skill as they may have for this class of creative work.

PRACTICAL BOAT CONSTRUCTION.

Within the limits of the present series of articles it will be quite impracticable to undertake any comprehensive discussion of the art of boat building. Brief consideration may, however, be given to the general principles which underlie the work of the boat builder, and to the general methods whereby those principles are carried into practical effect.

The fundamental purposes of the boat builder are two in number:

(1) The realization of the desired form.

(2) The provision of the necessary strength.

The principles and practice of boat building, therefore, circle about these two things, *form* and *strength.* The first has reference to geometry and the second to mechanics. Many other secondary purposes must, of course, receive due attention; such as those having relation to matters of convenience or comfort, and dependent primarily on personal taste. These are, however, of only collateral importance or interest, and we may therefore confine our attention to the principles which are involved in the attainment of the two main purposes— the realization of form and the provision of strength.

The first point to be made clear is that while the main purposes are thus stated under two heads, it by no means follows that two sets of structural members are to be provided, one set having special reference to form and the other to strength. Quite on the contrary, the skill of the boat builder is largely expended in devising ways and means for attaining most effectively both purposes by the same set of structural members, or in any event in avoiding as far as possible the use of members which relate to one of these purposes alone. The boat builder's ideal in such matters is naturally a structure in which both the determination of form and the provision of strength shall be provided by substantially the same sets of structural members.

Turning now to the question of form, it is clear that the actual form of the surface of the boat will be determined by the outer skin or planking. But planking alone cannot be assembled in the proper form without something over which it may be bent or formed as desired; and even when so bent the planks would scarcely retain permanently their form without an internal framework or stiffening which shall be permanent in form by itself, or rather which with the planking shall make a combination permanent in form under the conditions of service intended. The fundamental feature in the realization of form is therefore the planking. In fact the planking is in a sense the essence of the boat—all else is auxiliary or secondary—and to realize the planking two things are necessary:

(1) Frames or forms of some kind over which the planking may be bent and secured in shape.

(2) Some permanent internal stiffening or frame work which shall serve to assist the planking in maintaining the form given to it.

At this point we find two different practical methods of boat construction. In one which is quite commonly employed in building canoes, rowboats and quite small motor boats and launches, the forms over which the planking is bent are simply wooden molds put in place temporarily, their sole purpose being to bring the planking to the proper form for the outer surface of the boat. In the second type, which is always used for larger boats, the internal framework, consisting of frames and cross ties or deck beams, is formed and erected in place first, and the form of the boat is thus determined in skeleton. The planking is then bent over the frames and secured to them, and is thus brought to the form desired. In this case, therefore, the forms over which the planking is bent constitute a permanent part of the structure. Fig. 48 shows a boat set up with molds and the form thus determined, and illustrates the distinctive step in this mode of construction. Fig. 49, on the other hand, shows a boat in frame, with the form determined in skeleton, and thus illustrates the distinctive feature of the other mode of construction.

We must now turn to a consideration of strength, which we may conveniently examine under three heads:

(1) Longitudinal strength.
(2) Transverse strength.
(3) Local strength.

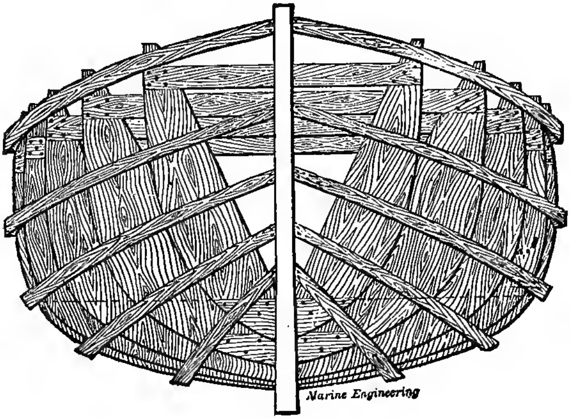

FIG. 48. BOAT SET UP WITH MOLDS.

By longitudinal strength we mean the capacity to resist bending of the boat as a whole, or any general distortion in the fore and aft lines.

By transverse strength we mean the capacity to resist such distortion as would produce a change of form in the transverse sections, or in their relation to each other, as by a gradual twist about a fore and aft axis.

By local strength we mean the capacity to resist local stresses of such a character as may tend to pierce or tear the hull at some particular point, but which may not necessarily tend to produce any general distortion or change of form in the boat as a whole.

With reference to longitudinal strength, the boat must be treated as a beam or girder, and must contain longitudinal members so disposed as to give the needed strength and stiffness in this direction. To this end the planking naturally contributes very largely, and as a rule only certain supplementary members are required, chiefly near the top and bottom of the boat, considered as a girder. For such purposes some combination of keel, keelson, sheer strakes, deck and side stringers, clamps and fender pieces may be fitted. These various members are illustrated in Fig. 50. Only rarely would they all be fitted in one design. In Fig. 51 is also shown the arrangement adopted in a case of actual design, and illustrates good practice with reference to these details. In Figs. 52 and 53 are likewise shown sections of a boat of the extreme high speed type, the former

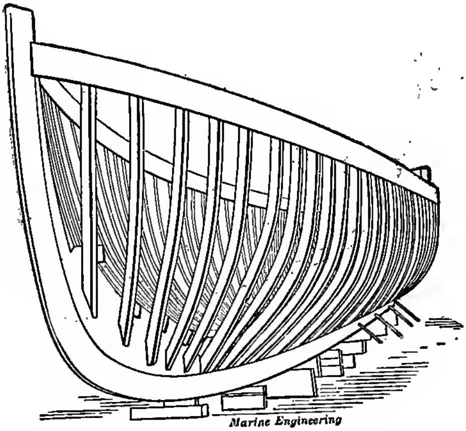

FIG. 49. BOAT IN FRAME, READY FOR PLANKING.

about amidships showing the engine under a turtle back, and the latter aft near the rudder showing the stern nearly resting on the surface of the water. See also Figs. 33 and 35.

Turning now to the question of transverse strength, we find that the planking, together with the internal framing over which it is fitted, provide together the primary or chief item of strength in this direction. These parts in particular, therefore, represent the double use of structural members—for the determination of form and for the provision of strength. It is clear that the spring of the frame and that of the planking will naturally oppose each other, and that out of this equilibrium under opposite forces there will arise a degree of strength with regard to transverse distortion. The weak part of such a structure as illustrated by an absolutely empty shell made up of planking and frames will clearly be at or near the gunwale, where the equilibrium of planking and frames would be difficult to secure or to maintain, and in consequence of which the sides would tend either to open out or to collapse, thus in either case changing the effective beam of the boat. To remedy this defect, deck beams, serving either as struts or as ties, as may be needed, are fitted except in the way of cockpits or other deck openings. Here deck stringers as shown

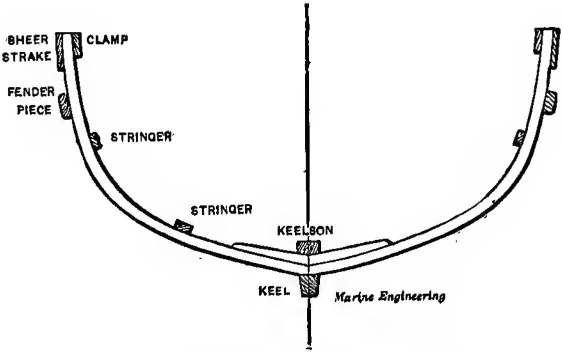

FIG. 50. MIDSHIP SECTION, SHOWING LONGITUDINALS.

in Figs. 51 and 52 are fitted, thus supplying at these points the needed special strength against transverse distortion. The laying of the deck planking on the deck beams adds also its quota of transverse strength against compresssive stress, though the primary purpose of the planking must be put down as shelter or convenience rather than as transverse strength.

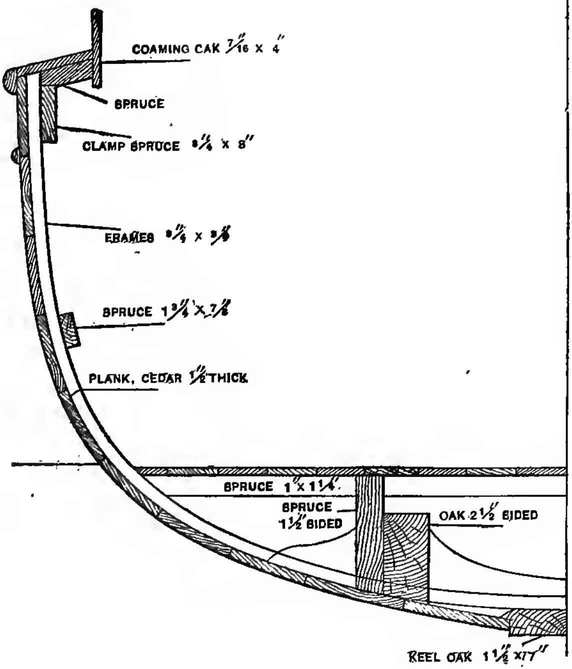

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FIG. 51. MIDSHIP SECTION OF 35-FOOT SPEED LAUNCH.

So far furthermore as the deck planking is continuous fore and aft, it adds an important item to the schedule of members furnishing longitudinal strength, and its possible function in this direction should therefore not be overlooked.

The function of the floor as an item of transverse strength should also be noted. The floor is a transverse vertical board or piece of thin planking, secured to the bottom of the frame and extending from side to side across the keel. In the way of cockpits the upper edges of a series of such floors are lined up so as to form the foundation for the bottom of the pit or opening. The function of the floor is to tie across and consolidate the frames, skin planking and keel at the bottom of the boat, and thus to give strength and stiffness along the keel with reference to transverse or twisting distortion, and to furnish an element of support at the keel, considered as a joint about which the two sides of the boat may tend to work when subjected to transverse forces.

Coming next to the question of local strength, it is naturally found to result that except at special points the needed local stiffness and strength may readily be provided by the members intended for general strength in the transverse and longitudinal directions. Hence for the construction in general no special provisions are required for local strength, and it is only at special points, such as about the stem and fore-foot along the side where contact with a dock may be likely, under the engine, about the propeller shaft supports, as in Fig. 53, etc., that structural members specially intended for local strength are introduced.

Local strength at the bow and at occasional other points in the framing is secured by filling in with chock, angle or knee pieces as shown by the cuts of longitudinal sections. Local strength along the side may be secured by a special fender or rubbing strip as shown in Fig. 50. Local strength under the engine is secured by a special foundation formed usually of longitudinal timbers or of structural steel which are intended to connect with the structure of the boat, and so lead away gradually into the structure of the boat as a whole the local stresses developed at the engine—see Fig. 51. A particular caution may be given here to avoid making such special foundation too short or too localized in character. It should be remembered that the real support of the engine is the boat, and that the object of the foundation is to give local strength and to bring to the support of the stresses developed, the maximum amount of actual boat structure.

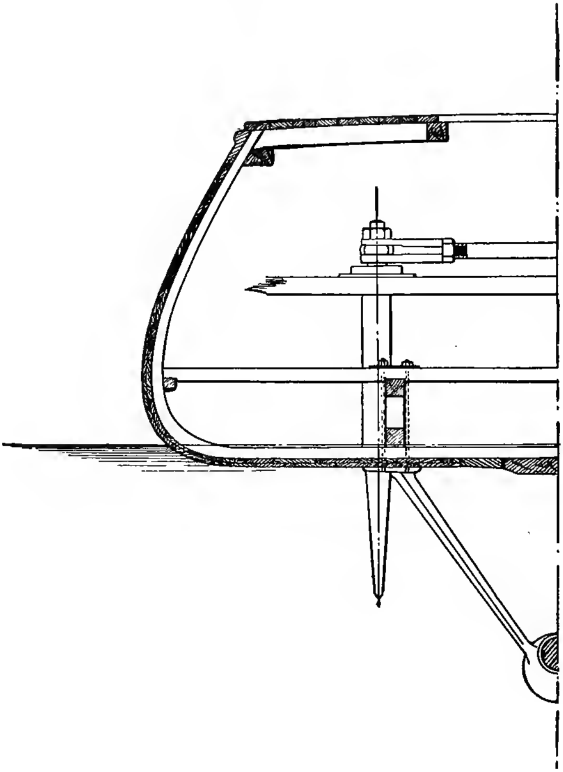

FIG. 52. SECTION OF VERITAS IN WAY OF RUDDER.

Turning now to the chief structural members of the boat, brief memoranda may be noted regarding materials commonly employed, and the characteristics best representative of present practice with regard to such items. We shall first assume the construction to be of wood, as is the more common practice for small boats of the type and character under consideration.

Keel. This is commonly of oak, and for the older form of stern more or less square in section, or with the greater dimension vertical, as indicated in Fig. 50; while for the more modern or torpedo boat stern, the flat keel, as indicated in Fig. 51, is more commonly employed.

The stem and the stern post, where fitted, are also commonly of oak and joined to the keel with oak or hackmatack knees.

Frames. These likewise are commonly of oak, from ½ inch to ¾ or 1 inch square, and spaced 6 inches to 8 or 9 inches between centers, both size and spacing increasing with the general size of the boat, and varying otherwise with the general character of the construction.

Deck Beams. These may be of oak (sometimes of spruce or even pine) and are spaced to suit the frames, and in section may vary with size and general character of construction from ½ to 1 inch in width by 1 to 2 inches in depth.

Deck Planking. This is commonly of pine or cedar, ⅜ to ½ or ¾ inch thick, and often covered with canvas laid in white lead or varnish, as a water-proof covering.

Side Planking. This may be of cedar, pine or mahogany, either single or double, and may vary in total thickness from as little as ¼ inch to 1 inch or more, according to size and character of construction. In ordinary construction, where saving of weight is of no special importance, one layer of ⅞- to 1-inch or even 1⅛-inch stuff represents in general the most serviceable form of planking in proportion to the expense involved. In such form of outer covering special attention must of course be given to the seams with reference to painting and calking, points which will be taken up at a later time. A much more generally satisfactory covering, especially with reference to the ease of keeping water-tight, may be obtained by the use of two layers each ⅜ to ½ inch in thickness, with white lead between and with the joints

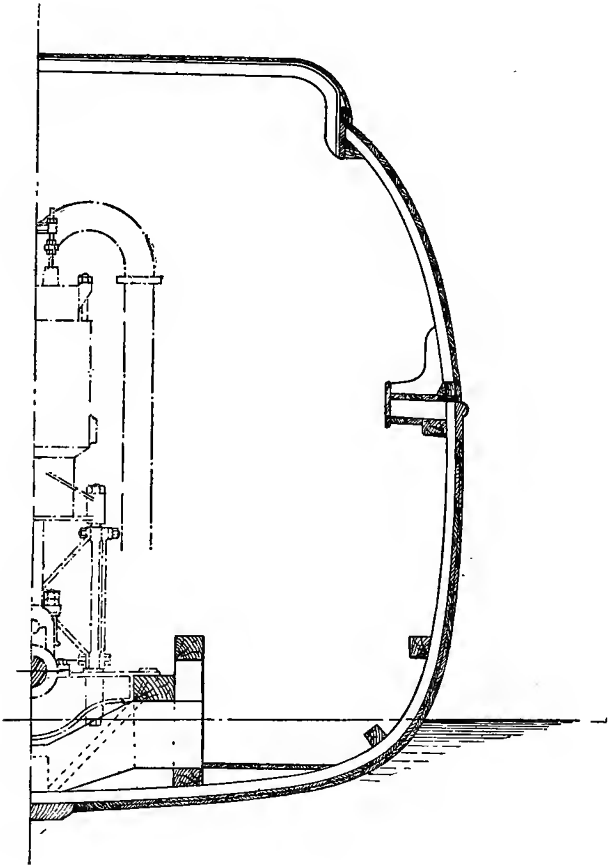

FIG. 53. SECTION OF VERITAS ABOUT AMIDSHIPS.

carefully shifted as between the inner and outer layers. In special construction for high speed boats, cedar or mahogany in layers ¼ or 5/16 inch thick is employed, and sometimes with a layer of silk or like fabric carrying oil or varnish as a form of stop-water between the layers of wood.

Fastenings. These may be copper rivets and burrs, copper nails clinched or riveted over burrs, screw fastenings of various and special forms, or plain galvanized iron nails and common screws. In all first class work only copper, brass or special bronze is used for fastenings, and wherever practicable they should be "through and through" rather than driven."

Water-tight Bulkheads. In the best modern practice it has become customary to provide for the subdivision of the boat into water-tight compartments by means of bulkheads which must be very carefully designed and fitted, with reference to both strength and water-tightness. From three to five such compartments are considered suitable in cases of typical modern design. The purpose should be to so proportion these compartments that the boat may still float with any one of them open to the sea.

In the ordinary boat with open cockpit there is usually scant room for such compartments at the bow and stern, especially if relatively large seating capacity in the cockpit is desired. If, however, the maximum of seaworthiness and safety is required, the central space must be cut down to such a point that the compartments at bow and stern can be made of size sufficient to give a small reserve of buoyancy, even with the central cockpit flooded. These are matters which turn chiefly on the question of policy—the extent to which safety is to be sought at the loss of some degree of capacity or convenience in smooth water. The question is one, in any event, which should be carefully considered, and the most recent and representative practice seems to indicate an increasing purpose to combine the highest practicable degree of safety with such other features as the design may contemplate, and to give full value to the importance of water-tight compartments in the consideration of these general questions.

It should be noted that in many respects there exists the widest range of practice between the construction of an ordinary moderate speed motor boat for runabout purposes and the special high speed racing machines, where the conditions for high speed are carried to the farthest possible extent, and involving most careful study of structural features in order to realize the maximum of strength and stiffness on the minimum of structural weight. Certain special features of construction found in boats of this type may be summarized as follows:

(1) Depending on the size of the boat, the frames are reduced in section and made of carefully selected material with a somewhat reduced spacing to offset, at least in part, the decrease in local strength caused by the reduction in thickness of side planking. With proper care in design the general balance between increase in number of frames and decrease in sectional area may be made to yield an important saving of weight as compared with the more ordinary schedule of construction.

(2) The side planking is commonly in two layers each $\frac{3}{16}$ to $\frac{5}{16}$ inch thick. In certain cases, however, a single layer of such covering is used, the seams being covered on the inside with strips worked as stringers, thus avoiding the need of calking, and effecting a saving in weight as compared with the more common double plank covering.

(3) Special diagonal bracing on the inside of the frames may be worked, adding strength against torsional stress, and aiding in the general consolidation of the framework together into an engineering structure.

(4) In certain cases special girder-like structures with top and bottom chords, timber struts for compression and steel wire for tension, have been worked along the sides of the boat inside, to aid in giving the necessary longitudinal strength against sagging and hogging stresses.

(5) Special forms of framing have been employed, as in the case of the *Standard,* and as a result of which marked saving of weight has been effected. The following brief description will give the principal features of the special framing employed in this case:*

The length over all is 60 feet and on the water line 58 feet, with an extreme beam of 7 feet 6 inches. The planking is of single thickness Honduras mahogany $\frac{3}{16}$ inch thick, and with edges secured by flush screws to continuous longitudinals of Oregon pine, after the manner noted in (2) above. The framing is carried out on a special double system consisting of inner and outer frames and longitudinals. The longitudinals are notched over the outer frames, and all three parts of the structure are through riveted, giving great transverse strength on a minimum of weight. The inner frame is furthermore carried continuous up the side and across, forming the lower member of the deck beam, while the upper member of the same runs across from side to side and ends at the plank-sheer. The longitudinal strength of the boat is obtained chiefly from two truss girders running from end to end in the wings, and consisting of upper and lower continuous longitudinals, wooden compression struts and galvanized wire diagonals set up tight, substantially as noted in (4) above.

(6) Local stiffening is reduced to a considerable extent by accepting a narrower margin of safety in this direction, and by a careful study of the disposition of the material in such manner as to realize maximum strength for minimum weight.

As a result of special construction along these lines, results have been realized giving a weight of hull of about one-third the total ultimate displacement as compared with one-half to two-thirds for more ordinary modes of construction.

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* See Marine Engineering, March, 1904, page 127.

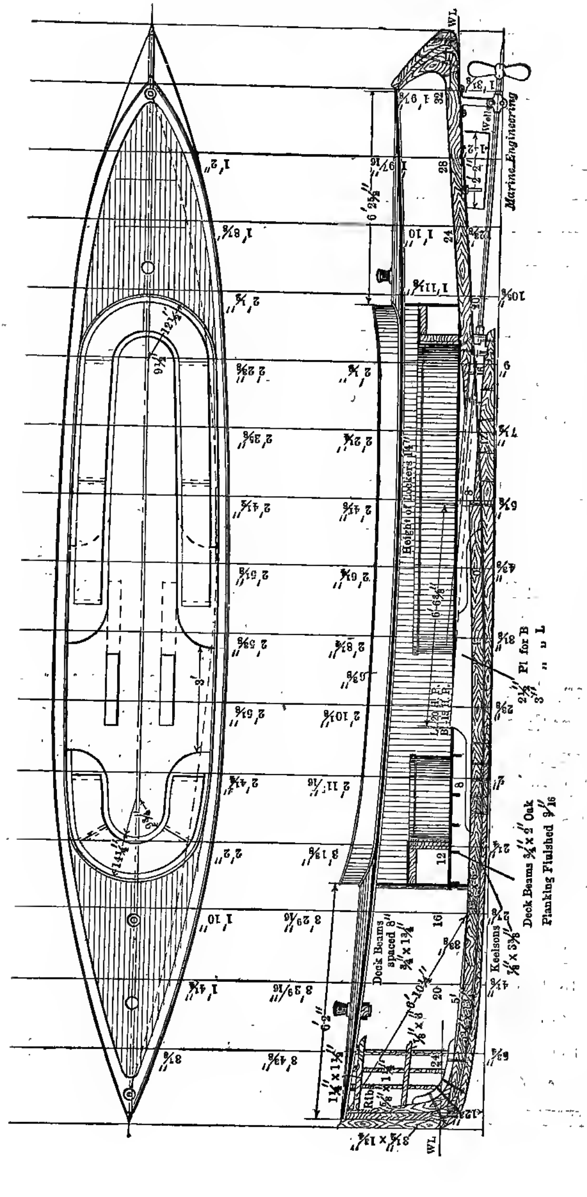

FIG. 54. INBOARD PROFILE AND DECK PLAN OF SPEED LAUNCH EUSONIA.

The use of structural steel for motor boats may be passed over with but brief reference. While there are not a few boats of the general motor boat type, especially in the larger sizes, which are built of structural steel, yet it must be admitted that the typical mode of construction of such boats is of wood. In cases of steel construction, furthermore, the general characteristics are similar to those met with in larger craft, or in wooden construction as well. The framing is made up of deck beams, transverse angle iron frames, longitudinal keel plate and stringer angles, with plating disposed in much the same manner as for larger craft, and fulfilling the same general functions.

Having in view the foregoing brief discription of the principles involved in practical boat construction, it will be of interest to give in some detail the following description* of the scantlings and structural features of a typical modern high speed motor boat, in which several special structural features have been introduced, and which yet represents excellent practice with respect to the main lines of small boat design and construction. See also Figs. 52 and 53 for section of this boat.

PRINCIPAL DIMENSIONS.

Length over all	56 feet 8 inches
Length on deck	55 feet 8 inches
Length on water line	54 feet 4 inches
Extreme beam	7 feet
Draft	3 feet

The boat is constructed almost entirely of wood, with fastenings of copper and Tobin bronze. At a few points castings have been used of gunmetal or manganese bronze.

The keel is of white oak made in two lengths, having a width of 4 inches at the forward end and increasing to 10 inches amidships, at which width it is continued to the stern post. The scarf between the two sections of keel has a length of 24 inches, and is fastened with five ¼-inch copper rivets and two brass screws. The keel is rabbeted to receive the side planking. The stem is of chestnut, secured to forward end of keel by means of a 32-inch scarf. The stern post is of white oak 4 inches deep,

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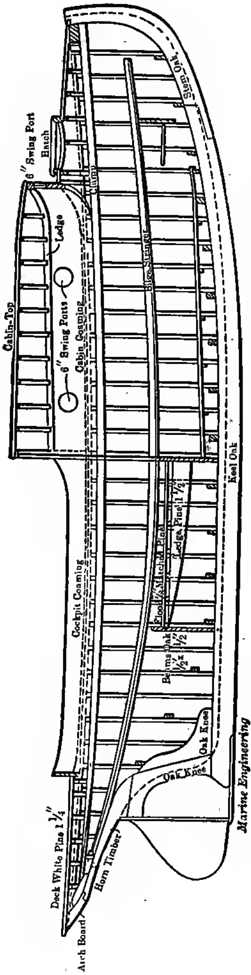
*See MARINE ENGINEERING, September, 1905, page 372.



Marine Engineering

FIG. 55. LONGITUDINAL SECTION OF SMALL MOTOR BOAT, SHOWING FRAMING.

and secured to the after end of the keel and to quarter timbers by means of a hackmatack knee.

The frames are of selected white oak, extending in one length from the plank sheer to keel, from the stem to frame number 60 inclusive. In the way of quarter timbers the frames are in two lengths, connected by a hackmatack knee. From frame number 60 to quarter timbers the frames overlap the keel or center line, reaching a maximum of 16½ inches at frame number 40. All frames are spaced 8 inches between centers, and measure ⅞ by ⅞ inch at keel and ⅞ by ¾ inch at head. The frames between numbers 32 and 53 extend up above the plank sheer to form coaming and sides of turtleback.

The floors forward of frame number 59 are of white oak measuring 1¼ by 1½ inches. Side keelsons of Oregon pine are fitted measuring 2½ inches on the siding from frame 15 to frame 59 inclusive, and diminishing to 1½ inches at the ends. The top strake measures 2½ inches for three-fifths length amidships, and 1½ inches at ends, while the figures for the bottom strake are 1½ inches and 1 inch respectively. These keelsons are connected by hackmatack floors with cedar braces and stiffeners, and also by occasional 2- by 2-inch spruce struts. Engine keelsons measuring 2½ by 3½ inches extend from frame 38 to frame 53, and carry the weight of the machinery.

The deck beams are of white oak 1¾ inches by 1 inch, except that beams at frames numbers 1 and 4 are 1¾ by 1¾ inches, and at numbers 6 and 32, 1¾ by 2½ inches, the latter dimension in each case being the siding or width. All beams are spaced one on each frame and crowned 2 inches amidships, except as modified by the turtleback structure.

The sheer strake is of white oak ⅞ inch in thickness and about 4½ inches wide, the lower edge being rabbeted to receive the double planking. It is worked with a molding 1$\frac{3}{16}$ inches in thickness as shown on sections. The bilge stringers are of clear Oregon pine in one length, 2 by 2 inches for three-fifths

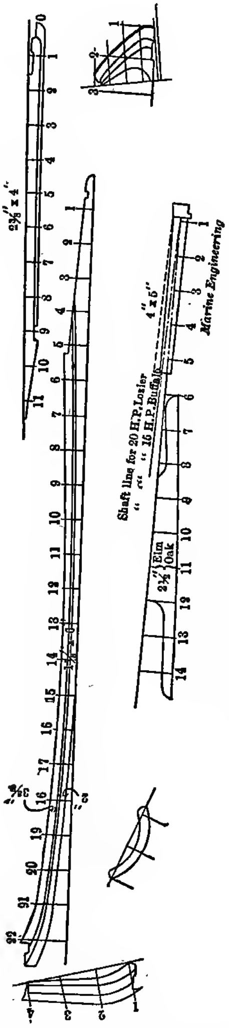


FIG. 56. DETAILS OF KEEL, STEM AND STERN, OF EUSONIA.

length amidships, tapering to 1½ by 1½ inches at the ends. The planking is in two thicknesses, with a width of 4 inches on the sides, increasing to 5 inches on the bottom. The inside thickness is of cedar, 5/16 inch thick, and the outside of mahogany, ⅜ inch thick. These are separated by Union silk covered with varnish, and are held together with button-headed brass screws.

The plank sheer is of mahogany, ⅝ inch thick on outside and ½ inch on inside and 4½ inches wide, fastened to each beam and to edges of sheer strakes with brass screws. The deck plank is of white pine ½ by 2½ inches at the stern and amidships, and ⅜ by 2 inches on turtleback, the seam being laid in white lead.

There are three bulkheads, located respectively on frames 6, 32 and 59. All are constructed of white cedar in two diagonal layers each ¼ inch in thickness, with a layer of Union silk between, covered with varnish, and all fastened together with copper rivets.

LAYING DOWN AND ASSEMBLING.

Having thus considered the structural elements best suited to the construction of small boats, a few points may be noted in connection with the actual process of preparing and assembling these elements into the completed structure.

The first step will be to lay down the water lines and the sections at each frame full size on the floor or mold loft. The ordinates for these lines are taken from the lines as designed, and the resulting full sized lines are faired up in the same general manner described in connection with the operation of design. It must not be forgotten that the lines as commonly laid down on the drawing board relate usually to the outside of the frame or inside of the skin. In such case they are immediately available for determining the form of the frames. Some designers, however, prefer to lay down the lines to represent the actual water surface of the boat, and in such case the thickness of the planking must be taken off all along the section line in order to obtain the form for the frame.

If we assume that the boat is of moderate or small size and is to be built over fixed molds, the next step will be to determine the form of the molds. Not less than five such molds should be used in addition to the stem and stern post or form, and in some cases a still larger number will be found advantageous. The form of the mold is to be taken from the full sized sections, one-half on a single board, selected of width sufficient for the purpose, and this used as pattern for a duplicate, the two then being put together as in Fig. 57, thus forming the mold complete.

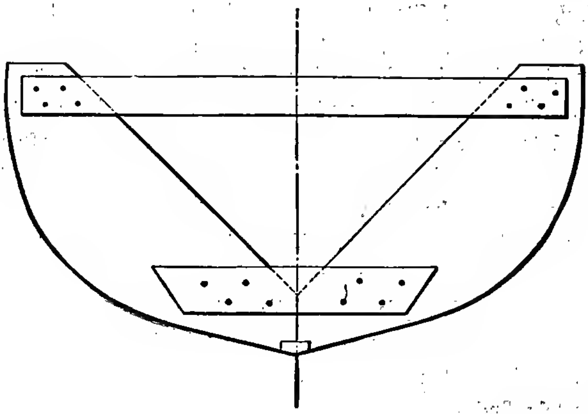


FIG. 57.

The form of the half section may be conveniently transferred from the floor to the board by laying down nails with their heads on the line of the section and the body standing at right angles. The board is then laid down on the nails and lightly pressed or struck with a hammer, thus making an imprint of the nail heads on the under side. A batten sprung through these will then give a satisfactory reproduction of the line on the board, and the mold may be cut to this line. Points showing the vertical center line are also noted, and from the half mold thus determined its mate is cut, and the two are joined as indicated in Fig. 57. The other molds being made in the same manner, the entire series is ready for assembling on the keel. The keel support may then be prepared, consisting of a two-inch plank blocked up on edge, and with the upper edge cut to fit the sweep of the keel. This plank, which is, of course, no part of the boat proper, makes a convenient and secure foundation for the further construction of the boat. It will be found a convenience to so adjust this support as to bring the designed water line of the boat horizontal.

Keel, Stem and Sternpost. These items may next be gotten out to dimension, and suitably rabbeted to take in the edge of the garboard strake of planking and the ends at the stem and stern. They are then erected in place on the keel support, and secured together with chocks and through fastenings after the manner indicated in the various illustrations showing structural features of this character.

Deadwood and Shaft-log. With the old form of stern the deadwood and shaft-log may next be gotten out and fitted in place. The shaft log is usually formed by a pair of timbers secured by through bolts, and provided with a longitudinal hole of size suitable for the shaft tube, and within which the shaft will ultimately find its place.

In the framework throughout, and especially in these longitudinal members, the joints between the timbers should be made tight with white lead and drawn close by means of through fastenings wherever possible.

Molds. The molds, made as above noted, may now be erected in place, centered and squared with the keel, and then secured by bracing and ties.

Ribbands. These are strips which are bent over the molds and lightly secured to them from one end to the other along the planking lines. These will serve to further secure the molds in place, and will also indicate any unfairness in the lines, should such exist. It will be an advantage to make the molds of sufficient height so that the upper ribband may be put on clear of the location of the sheer strake, thus providing a line of support for the frames until the sheer strake and clamp piece are secured in place. In small boats, furthermore, the ribbands are readily made of sufficient size and number to permit the frames to be bent into place against them and thus formed without the use of frame molds or bending floor.

Frames. The material for the frames may next be prepared, and the frames bent to form and secured in place. As noted above, small frames may be bent directly in place against the ribbands. After being properly sized, the frame is steamed and then taken directly to place and bent to form, secured to the keel, clamped to the ribbands and carefully adjusted in place. For heavier construction, where the frames cannot be readily bent against the ribbands, they are commonly brought to form on the bending floor. To this end the form of the frame on the inner or concave side is transferred in any convenient manner to the floor, and holes are bored along the inner edge, into which pegs are driven and against which the frame is then readily bent to form. In some cases, however, special molds are cut out for each frame and used as a foundation on which to bend the frame to form. Where the form of the frame will permit, it should run continuously from rail to rail, without joint at the keel. This however will be practicable only amidships; while forward and aft, where the angle at the keel is sharp, the frame will be made in two parts, secured together by a chock at the bottom. In either case, after being bent to form, the two sides of the frame are secured by cross ties so that it will retain its form when erected in place in the boat. When adjusted in place the frames may be secured permanently to the keel and temporarily to the ribbands. The fastening to the keel will include the fitting of chocks or bent floors with keelson, somewhat as indicated in Fig. 50.

Planking. This is to be gotten out in as long lengths as possible, tapered toward the bow and stern so as to carry the same number of strakes all the way fore and aft, and maintain as far as possible the planking edges at right angles with the frames.

Where the planking is double, the outer layer must be so arranged as to shift joints with the inner layer. The outer surface of the latter may be painted with thick white lead with special attention to the end joints and seams, and the joints and seams of the outer layer should be made with the same or equivalent material. This will give a white lead filling in all joints and seams and between the two layers, which will serve effectively to make a watertight job of the planking as a whole.

The ribbands are, of course, removed in order to make way for the planking, except in the case of the upper ribband, which, as noted above, should be carried high enough to clear the sheer strake and clamp piece. After the latter are fitted and secured in place a few ties may be run across from one side to the other, the upper ribband removed, the tops of the frames sawn off, and the molds removed. The rail may then be finished as desired, either left as formed by the combination of sheer strake, clamp and frames, or with the space between the frames filled in, or with a cap piece covering over the sheer strake, clamp and space between.

Bilge and Side Stringers. In all first class construction and in all but the smallest boats, these should be fitted as a general addition to the longitudinal strength and stiffness of the boat.

Engine Bed. The general principles relating to the installation of the engine bed have been already discussed. The details will depend on the special design of the engine. Special precaution should be taken to avoid making it too short or too light, and particularly in high-powered boats, too great care can not be taken in so arranging the engine bed as to call into play the maximum amount of boat structure.

Seats. Whether the seats are run fore and aft or athwartships they should be supported on the skin of the boat by a suitable stringer piece run on the inside of the frames and secured to them. The seat should then be carefully secured to the supporting stringer in order that it may act as a tie or brace for the side of the boat. Transverse seats thus fitted give the boat great lateral strength, acting as ties or struts as occasion may demand, while a longitudinal seat fitted in the same manner will act in effect as a powerful side stringer, adding in marked degree lateral stiffness to the side of the boat. With fore and aft seats, the inner edge is of course carried on posts extending down and carried on a stringer piece attached to the frames. In some cases chocks are fitted under the seats to give added racking strength to the boat.

Deck Beams and Decks. Deck beams and decks over the covered spaces may be fitted next, not forgetting the installation of gasoline tanks or of any such feature which is to go in before the space is finally closed.

Planing and Finishing Exterior. After the preceding work is completed, the work of planing and finishing the exterior may be taken up. The planking is first rough planed, and the joints are then calked and filled with thick white lead or similar material. The surface may now be finally planed and smoothed up and made ready for painting and puttying. Much will here depend on the eye. The relatively thin planking will not permit the removal of any great thickness in order to fair up a part of the surface which may seem too high, and in order to realize the best result as regards external finished form, great judgment and care will be required. These facts call all the more emphatically for special care with the form during the earlier stages, and before it is too late to change the molds and correct any irregularities which may exist. If this part of the work is well done the form of the boat will, under the plane, scraper and sandpaper, come out smooth, continuous and pleasing to the eye.

Where the planking is worked in a double layer, the calking is unnecessary, though with thick planking it is sometimes employed. With thin planking, such as ¼ to ⅜ inch thick, however, it would be found very difficult to make the seam retain the cotton. For this reason, among others, when very thin planking is to be used it must be worked in double thickness with shifted seams, thus obviating the need of a calked joint.

In painting, three or four coats will be none too many, rubbed down somewhat between each coat, and with plenty of time for drying allowed. This, if well done, will give an outer surface smooth, hard and durable. Below the water line some good marine or anti-fouling paint may be used, while above, good white lead, or color in a white lead base, is to be recommended.

Thus far the type of construction more especially in view is the small boat made over molds and with dead-wood and the old form of stern. With larger boats of the same general type the frames will be heavier and stiffer, and the use of molds is no longer needful or common. The frames are prepared, bent to form and secured in place all in the same general manner as described. This operation being completed, the boat is then "in frame," and the planking and other structural and finish features are carried out along the same general lines as for the smaller type of construction.

For boats with the torpedo-boat or modern stern, the constructive operations are of the same general nature, and involve the same underlying principles as for the older type. With the modern stern the keel is usually flat rather than bar-formed —the more common style of keel with the older stern. These differences are shown in the various structural views.

A further item of difference is found in the dispositions suitable for taking care of the shaft and shaft tube where it passes through the bottom of the boat. Suitable material must be provided at this point, as indicated in the structural cuts, in order to properly secure the tube to the boat and give adequate support to the shaft. In addition to the bearing for the shaft where it passes through the bottom of the boat, there will also be required an additional support at the extreme end of the same, just forward of the propeller. This is usually in the form of a hanging bracket formed of structural steel or cast bronze, and supporting a suitable bearing for the shaft, the general arrangements being indicated sufficiently in the various illustrations.

The style of boat construction in view throughout these suggestions is of the plain normal type, such as is met with in the average small or moderate sized motor boat, and where no special requirements involving extra speed or lightness are in question. For such special cases various structural features, including special methods of framing, extra thin planking with or without varnished fabric between, etc., have been noted at an earlier point, and will not require further mention here.

These brief hints regarding practical boat construction are furthermore intended only to outline the general processes, chiefly as illustrative of the principles dealt with at an earlier point, and as indicating to the non-technical reader the general routine of operations which may be followed in work of this character. It must be understood that there will be a vast number of problems of fitting, adjustment and procedure, with which the practical builder must deal as best he may, and which can not be covered in any written description of such work. Details of construction must vary with the particular features and requirements of the case, and in these pages no more is intended than to give some notion of the underlying principles involved, with sufficient illustration of their application to stimulate an intelligent study of such problems on the part of those who may be brought into contact with them.

POWER AND SPEED.

There is no problem in connection with the motor boat so hedged about with difficulty and uncertainty as that concerned with the relation between the characteristics of the boat and the power for a given speed, or the speed which may be expected for a proposed power. This is due primarily to the obscure character of the relation between the factors on which the resistance of a boat depends, and on the fact that no general formula or definite relation can be derived by purely theoretical methods. It results that experiment and experience are the only sources of final and definite information, and for every boat which marks a new departure the experiment must be carried to a conclusion before definite assurance can be gained regarding these relations. On the other hand, every boat which is built, and regarding which definite results are available, becomes a basis for an indefinite series of boats of similar geometrical form, and driven at speeds related to that of the type boat by a simple geometrical factor. It is true that if the boats differ greatly in size the relation given by this law of comparison is less trustworthy. If, however, the difference in size is moderate or small, and the geometrical forms are similar, then the results of the one may be used with confidence for the design of the other.

In approaching the subject in somewhat further detail, we may first note very briefly the character of boat resistance. It seems natural in attempting to classify or analyze such resistance to proceed according to the manifest results. These may be divided into two general classes, as follows:

(1) A thin film of water composed of small eddies lying near the skin of the boat and surrounding the wetted surface somewhat like a blanket or sheath.

(2) General effects manifested in the form of waves and surface disturbances.

Each of these requires the expenditure of energy for maintenance in its position relative to the boat, and this means the manifestation of a resistance which must be overcome in order to maintain steady motion of boat relative to water. The sheath of eddy water is caused by forces similar to friction, and acting between the surface of the boat and the water. This part of the resistance is usually called the frictional or skin resistance. The part of the resistance due to the maintenance of systems of waves and surface disturbances is usually called the wave making or residual resistance.

At low speeds the skin resistance forms the principal part of the total, while the wave making resistance is comparatively of small importance. As the speed increases, however, the wave making resistance rapidly increases in relative importance. At moderately high speeds it will form one-half, and at extreme speeds more than one-half, the total resistance. It thus appears, as previously noted, that at low speeds the form of the boat should be designed with some reference to the reduction of surface, and hence of skin resistance; while at high and extreme speeds the form must be chosen with special reference to the reduction of waves and surface disturbances.

The skin resistance increases with the speed by an index somewhat less than 2. That is, this part of the resistance varies somewhat more slowly than as the square of the speed.

The wave making resistance varies with the speed according to a somewhat variable index, found usually between 3 and 5. It results that the total resistance at moderate speeds, when the wave making part is small, will vary with an index not far from 2, while as the speed increases, not only does the resistance itself rapidly increase, but also the average index according to which it varies with the speed.

Returning now to the main problem of power and speed, it must be understood that the practical rules and methods which are given in the present chapter represent the results of experience on craft of the general motor boat type, as regards form and size, and that the basis for the use of such rules and methods is therefore practical rather than theoretical. On the other hand, it must be realized that no method or formula can be applied to the treatment of such questions without a considerable infusion of judgment, based preferably on experience with problems of this character.

The two questions which arise in this connection are as follows:

(1) What power will be required for a proposed speed?

(2) What speed may be expected with a proposed power?

The one problem is, of course, the inverse of the other, and the solution of either carries with it that of the other.

We shall give two methods for the treatment of these problems, the first based on the so-called law of comparison, and intended for the application of the known results with a given boat to the design of another of similar geometrical form but of different size; and the second by the use of a formula direct, and independent of results drawn from other boats, except in so far as such results are used as a guide in selecting the value of the arbitrary "constant" in the formula.

Taking the law of comparison first, it should be noted that this law, strictly taken, is intended to apply only to the residual or wave making resistance, and that it can be applied only approximately to the skin resistance. This lack of application to the skin resistance is, however, only partial, and when applied to the problem of powering as a whole the results are at least as good as may be found by any other quick and practical method, such as is desired for the purposes of these pages.

It must be clearly understood that the law of comparison is intended to relate the power for a boat A at a speed v_1 to the power required for a boat B of similar form and at a speed v_2.

We must first define what is implied by the word similar.

Absolute similarity implies two or more boats made, so to speak, all from the same drawings, and differing only in scale. Such boats would possess absolutely identical geometrical characteristics and coefficients throughout, and would fulfil the full content of the term similar. On the other hand, substantial similarity will be insured if the proportions between length, beam and draft do not differ sensibly between the two boats, and if the general form characteristics and coefficients as discussed in the chapter on design are of closely similar values. In general it may be said that the more closely the two boats approach to full geometrical similarity the more reliable will be the results of the application of the law of comparison; while as the two forms under consideration depart more and more widely from such complete similarity, the less trustworthy will be the results indicated by the application of this law.

We must next relate the speeds v_1 and v_2. These are said to "correspond" or to be "corresponding speeds," and are defined by the following simple proportion:

Let L_1 and L_2 denote the lengths of the two boats. Then we have:—

$$v_2 : v_1 :: \sqrt{L_2} : \sqrt{L_1}$$

$$\text{or } v_2 = v_1 \sqrt{\frac{L_2}{L_1}}$$

In words we may say that corresponding speeds are proportional to the square roots of the lengths. A few illustrative examples will make this clear:

Boat A is 36 feet long, and boat B, similar in form, is 25 feet long. The speed of A is 12 miles per hour, what is the "corresponding speed" for B?

From the formula we have:

$$v_2 = 12 \sqrt{\tfrac{25}{36}} = 12 \times \tfrac{5}{6} = 10 \text{ miles per hour.}$$

Boat A is 30 feet long, and boat B, similar in form, is 50 feet long. The speed of A is 18 miles per hour, what is the "corresponding speed" for B?

From the formula we have:

$$v_2 = 18\sqrt{\tfrac{50}{30}} = 18 \times 1.29 = 23.22 \text{ miles per hour.}$$

We may now state the law of comparison for power as follows:

The horsepower required to give corresponding speeds in two boats of similar geometrical form will be in the direct ratio of either:—

(1) The seven-sixths power of the weights or displacements, or

(2) The seven-halves power of the lengths.

Thus, denoting the powers in the two cases by H_1 and H_2, and the weights or displacements by W_1 and W_2, we have algebraically:

$$H_2 : H_1 :: W_2^{\frac{7}{6}} : W^{\frac{7}{6}}$$

$$\text{or } H_2 = H_1 \times \left(\frac{W_2}{W_1}\right)^{\frac{7}{6}}$$

$$\text{Or, again: } H_2 : H_1 :: L_2^{\frac{7}{2}} : L_1^{\frac{7}{2}}$$

$$\text{or } H_2 = H_1 \times \left(\frac{L_2}{L_1}\right)^{\frac{7}{2}}$$

We may also indicate the operations of these formulas by the following step by step rules:

(1) Divide the displacement of the proposed boat by that of the type or given boat. (Both displacements must be expressed in terms of the same unit, which may be either tons or pounds.)

(2) Find the value of the seven-sixths power of this ratio. This may be done as follows: (a) Take the cube root of the ratio. (b) Take the square root of the result found in (a). (c) Multiply the original ratio by the result found in (b), and the product will be the seven-sixths power desired. The square and cube roots will naturally be determined by the use of tables, such as those found in any of the engineering hand books.

(3) Multiply the power required by boat A at speed v_1 by the result found in (2). The product will give the power required for boat B at speed v_2.

Or, otherwise, using the length ratio:—

(1) Divide the length of the proposed boat by that of the type boat.

(2) Find the seven-halves power of this ratio. This may be done as follows: (a) Find the cube of the ratio. (b) Find the square root of the ratio. (c) Multiply the result found in (a) by that in (b), and the product will be the seven-halves power desired.

(3) Multiply the power required by boat A at speed v_1 by the result found in (2). The product will give the power required for boat B at speed v_2.

A few illustrative examples may now be given.

(1) Boat A is 30 feet long, with a displacement of 8,000 pounds, and is found to make 12 miles per hour with 20 horsepower. What information can be drawn from these results regarding a boat of similar form and 45 feet long, with a displacement of 27,000 pounds?

We have first:

$$v_2 = 12\sqrt{\frac{45}{30}} = 12 \times 1.22 = 14.64$$

$$\text{Then } H_2 = H_1 \times \left(\frac{27,000}{8,000}\right)^{\frac{7}{6}} = H_1 \times (3.375)^{\frac{7}{6}}$$

$$\text{Now } (3.375)^{\frac{1}{3}} = 1.50$$

$$\text{and } (1,50)^{\frac{1}{2}} = 1.22$$

$$\text{and } 3.375 \times 1.22 = 4.12$$

$$\text{Then } H_2 = 20 \times 4.12 = 82.4$$

We therefore conclude that the larger boat, with a length of 45 feet and a displacement of 27,000 pounds, at a speed of 14.64 miles per hour, would require 82.4 horsepower. It should be noted in particular that this method gives us no indication as to how much power would be required by the larger boat at the *same* speed as the smaller, but only at the higher or *corresponding* speed.

(2) Suppose boat A is 30 feet long, as before, but with a displacement of 3,000 pounds, and with a speed of 21 miles on 45 horsepower. What can be inferred regarding a similar boat 24 feet in length?

In this case we shall have:—

$$W_2 = W_1 \times \left(\frac{24}{30}\right)^3 = 3{,}000 \times (.8)^3 = 1{,}536 \text{ pounds.}$$

$$v_2 = v_1 \times \left(\frac{24}{30}\right)^{\frac{1}{2}} = 21 \times (.8)^{\frac{1}{2}} = 18.77 \text{ miles per hour.}$$

$$H_2 = H_1 \times \left(\frac{24}{30}\right)^{\frac{7}{2}} = 45 \times (.8)^{\frac{7}{2}}$$

$$(.8)^3 = .512$$

$$(.8)^{\frac{1}{2}} = .894$$

$$.512 \times .894 = .458$$

$$H_2 = 45 \times .458 = 20.6 \text{ horsepower.}$$

We therefore infer that the smaller boat, with a displacement of 1,536 pounds, would show a speed of about 18.77 miles per hour, on 20.6 horsepower.

(3) Again, suppose boat A as in (2), and that we propose a boat B approximately similar, with a length of 36 feet, and a displacement of 5,000 pounds.

We then have:

$$v_2 = 21 \times \left(\frac{36}{30}\right)^{\frac{1}{2}} = 23.1 \text{ miles per hour.}$$

$$H_2 = 45 \times \left(\frac{5{,}000}{3\ 000}\right)^{\frac{7}{6}} = 45 \times (1.67)^{\frac{7}{6}}$$

$$(1.67)^{\frac{1}{3}} = 1.185$$

$$(1.185)^{\frac{1}{2}} = 1.09$$

$$1.09 \times 1.67 = 1.82$$

$$H_2 = 45 \times 1.82 = 81.9 \text{ horsepower.}$$

We may next turn to the method of powering by the use of a formula direct. For this purpose we shall make use of the so called Admiralty Coefficient formula, in the following form:

$$H = \frac{A\,B}{K}$$

where: H = horsepower required,
A = factor taken from table I,
B = factor taken from table II,
K = factor to be selected by judgment as discussed below, and usually found between 200 and 500.

It may be noted that the values of A are found by taking the two-thirds power of the displacement in pounds, and dividing by 100. That is, $A = (\text{displacement})^{\frac{2}{3}} \div 100$. To find A accurately for values lying between those given in the table we therefore proceed as follows: (1) Take the cube root of the displacement. (2) Square the result found in (1). (3) Divide the result in (2) by 100 and the quotient will be the value of A. For most cases, however, the value of A may be taken with sufficient accuracy from the table.

Likewise, the values of B are the cubes of the speeds in miles per hour, and thus other or intermediate values may be found.

The values of K correspond to those of the Admiralty coefficient, and are in fact the numerical values of this coefficient, multiplied by 2.62 in order to reduce them to the units employed in the present formula. The value to be taken in any individual case must be based on judgment regarding the mutual influence of the three items, length, speed, form. Other things being equal, the value will be greater as the length is greater, as the speed is lower, and as the form is finer; and the value will be less under respectively opposite conditions, that is, as the length is less, as the speed is higher, and as the form is less fine. Somewhat otherwise, the value will generally be less as the ratio of the square of the speed to the length is greater, and as the ratio of beam to length, or the form coeffiicients are greater, and the value will be greater under opposite conditions. A short, wide, full form at relatively high speed will therefore require the lowest values of *K*, while a long, narrow, fine form at moderate speed will permit of the higher values. This means that the short full form at high speed will require relatively excessive power, and the long fine form at moderate speed will require relatively moderate power, each in relation to the cube of the speed. All this is, of course, in accord with the indications of common sense as applied to such problems.

TABLE I.—VALUES OF A.

Displacement	*A*	Displacement	*A*	Displacement	*A*
500	0.63	8,000	4.00	17,000	6.61
1,000	1.00	9,000	4.33	18,000	6.87
1,500	1.31	10,000	4.64	19,000	7.13
2,000	1.59	11,000	4.94	20,000	7.37
3,000	2.09	12,000	5.24	21,000	7.61
4,000	2.52	13,000	5.53	22,000	7.85
5,000	2.92	14,000	5.81	23,000	8.09
6,000	3.30	15,000	6.08	24,000	8.32
7,000	3.66	16,000	6.35	25,000	8.55

The question of what is a speed relatively high or low still remains. This will depend on length and form. For medium fineness of form speeds in excess of 1.2 times the square root of the length in feet will be relatively high, and to a degree increasing with the increase of speed. For very fine forms the limit beyond which the speed must be considered relatively high is pushed somewhat farther along—perhaps to 1.3 or 1.4 times the square root of the length in feet. In all cases, it should be remembered, speeds are here considered as measured in miles per hour.

Thus for a boat 25 feet in length, and of medium fineness of form, 6 miles per hour will not be an excessive speed, and

TABLE II.—VALUES OF B.

Speed, Miles	B	Speed, Miles	B
5.0	125	5.5	166
6.0	216	6.5	275
7.0	343	7.5	422
8.0	512	8.5	614
9.0	729	9.5	857
10.0	1,000	10.5	1,158
11.0	1,331	11.5	1,521
12.0	1,728	12.5	1,953
13.0	2,197	13.5	2,460
14.0	2,744	14.5	3,049
15.0	3,375	15.5	3,724
16.0	4,096	16.5	4,492
17.0	4,913	17.5	5,359
18.0	5,832	18.5	6,332
19.0	6,859	19.5	7,415
20.0	8,000	20.5	8,615
21.0	9,261	21.5	9,938
22.0	10,648	22.5	11,391
23.0	12,167	23.5	12,978
24.0	13,824	24.5	14,706
25.0	15,625	25.5	16,581
26.0	17,576	26.5	18,610
27.0	19,683	27.5	20,797
28.0	21,952	28.5	23,149

for such or lower speeds values of *K* from 350 to 450 might be safely used. If the form is very fine, then no serious increase of the power relative to the cube of the speed would be looked for below perhaps 7 miles per hour, and for equal speeds somewhat larger values of *K* would be indicated as compared with the preceding case. On the other hand, as the speed rises above 6 miles with medium fineness of form, the power will increase more rapidly than the cube of the speed, and the values of *K* must be correspondingly decreased to their lower range. The same will be true for the finer form, though not to the same degree. Thus for a speed of 10 miles per hour with medium form a coefficient of 250 or 275 might be suitable, while with fine form it might be increased to 300 or over.

For racing craft of specially fine form, of length 30 to 40 feet or thereabouts, and at extreme speeds lying between 20 and 30 miles per hour, specially large values of the coefficient have been realized in practice, indicating possibly a decrease of actual displacement and wetted surface at these extreme speeds, due to lifting of the boat, and in any event a relatively low value of the horsepower required, compared with the indications drawn from boats with somewhat fuller form and at lower speeds. Thus, in several cases of such craft, the values of *K* as determined by test lie between 350 and 550.

It will be seen in general that so far as the relation of length to square of the speed is concerned, motor boats as a class are all driven at relatively high speeds. Thus taking 50 feet in length as near the upper limit of the motor boat class, the rule given above indicate[illegible] speeds above 8.5 to 10 miles will be relatively high [illegible] length, and for everything shorter. In fact any motor boat not driven at a speed higher than 1.2 or 1.3 times the square root of the length in feet would be rated distinctly slow as a boat.

It results therefore that with motor boats as a class the speed is high relative to the length, the power is high relative to the cube of the speed, and the values of *K* must be taken correspondingly low in consequence. The question of chief practical importance concerns the extent to which this lowering of the value of *K* may be offset by fineness of form, and in particular to what extent extreme fineness combined with extreme speed may carry the case into a set of conditions justifying the use of relatively large values of *K*. Experience indicates that in most cases fineness of form does exercise a very important influence on the permissible value of *K*, and it is with the estimate of this influence that the judgment of the designer must be chiefly concerned. Experience also indicates, as noted above, that excessive fineness combined with extreme speed (especially with forms which naturally tend to lift at such speeds) may give conditions relatively economical for propulsion, and permitting the use of the higher range of values for *K*.

In this connection mention may be made of the motor boat *Napier II*, constructed in England for the purpose of demonstrating the possibilities of the skimming boat. The bottom is practically flat, and the lines are so adjusted that the boat tends to rise and run at an immersion continuously decreasing as the speed is increased. The results obtained by this boat seem to meet expectations in so far as the relation between speed and power is concerned. The boat, which has a length of 40 feet and a displacement of 7,170 pounds, reached a speed of about 30 miles per hour on 150 horsepower, indicating a value of 665 for the constant *K* as based on the original displacement. This value in itself indicates a marked decrease in displacement at these high speeds, a condition indicated also by observations on the boat itself under running conditions. It should be noted that, while such possibilities are plainly indicated for very high speeds, they must be purchased at some sacrifice of seaworthiness and weatherly qualities in rough water. The form of the bottom of this craft is such as to subject the boat to severe pounding in a seaway, and the entire design is essentially suited for smooth water conditions only. It may be concluded that, while in the average motor boat some advantage may be realized by the utilization of this principle, yet for the boat intended for average conditions of wind and weather, it can be applied only in small measure; and if stability and weatherly qualities in a sea way are desired, the boat must not be expected to run under conditions which will in marked degree decrease the immersion or the displacement.

We may now turn to a series of examples intended to illustrate the use of the above formula.

(1) Given length $= 36$ feet, displacement $= 12{,}000$ pounds, speed 9 miles per hour. This is an illustration of a boat of fairly large size at moderate speed and of medium fineness of form. The speed, while moderate for a boat of this character, is still somewhat high compared with the length, as indicated by the rules given above, and we must therefore choose a moderate value of the factor K—perhaps from 250 to 300. We have then $A = 5.24$, $B = 729$ and $H = 5.24 \times 729 \div 250 = 15$. If we use $K = 300$, we find similarly $H = 12$. Hence we conclude that from 12 to 15 horsepower should serve to fulfil the conditions as specified.

(2) Given length $= 33$ feet, displacement $= 3{,}600$ pounds, speed 15 miles per hour. Assume fine lines and general conditions favorable to high speed. In such case we may take $K = 300$. We have then $A = 2.35$, $B = 3{,}375$ and $H = 2.35 \times 3{,}375 \div 300 = 26$.

(3) Given length $= 24$ feet, displacement $= 4{,}800$ pounds, speed 7 miles. This is an example of a full form, slow speed, family runabout. The conditions indicate a value of K not much exceeding 250.

We have then $A = 2.85$, $B = 343$ and $H = 2.85 \times 343 \div 250 = 3.91$ or say 4 horsepower.

(4) Suppose we try to drive the boat of (3) at 8.5 miles. We should then reduce K to something like 200, and we have $B = 614$ and $H = 2.85 \times 614 \div 200 = 8.75$ horsepower.

(5) Given length $= 56$ feet, displacement $= 12{,}000$ pounds,

speed 25 miles. Assume fine lines and all conditions favorable to high speed. In such case we shall take $K = 350$. We have then $A = 5.24$, $B = 15{,}625$ and $H = 5.24 \times 15{,}625 \div 350 = 234$.

(6) Given length = 40 feet, displacement = 5,000 pounds, speed = 28 miles. Assume the utmost refinement with reference to high speeds. Under such conditions and at such a speed we shall be justified in taking $K = 500$. We have then $A = 2.92$, $B = 21{,}952$ and $H = 2.92 \times 21{,}952 \div 500 = 128$.

(7) Given length = 41 feet, displacement = 3,300 pounds, speed 26 miles. Assume conditions the same as in (6) and take the same value of K. Then we have $A = 2.22$, $B = 17{,}576$ and $H = 2.22 \times 17{,}576 \div 500 = 77$.

In some cases it is desired to make a rough estimate of the power, based simply on the dimensions, mean draft and speed, and without definite knowledge of the displacement. In such case it will be necessary to assume a value of the block coefficient as described in the chapter on the design of form, and using this with dimensions, the displacement may be found as indicated by the following example:

Given length 32 feet, beam 5 feet, mean draft 2 feet, speed 12 miles. Assuming that the form is fairly well fined away we may take the block coefficient at 0.45, and we find therefore for salt water: displacement $= 32 \times 5 \times 2 \times .45 \times 64 = 9{,}216$ pounds.

In connection with the general problem of speed and power it will be convenient to note here the relation between the power of a gasoline engine and the characteristics on which it depends. It will be remembered that the conditions differ from those with the steam engine on account of the difficulty of measuring the indicated horsepower of an internal combustion engine of the type, size and revolutions commonly met with in this field of service. Instead of the indicated horsepower, gasoline engines are usually rated by brake or delivered horsepower, representing the power actually delivered to the propeller shaft. In the discussion of such engines it often becomes convenient, furthermore, to refer to the rated power of the engine, based on the dimensions and revolutions per minute. Such power is computed by an arbitrary formula, of which several have been proposed. The simplest of such is in the form:

$$H = \frac{N\,A\,L}{C}$$

where: N = revolutions per minute,
A = the sum of the areas of all pistons, expressed in square inches.
L = length of stroke in feet.
C = a constant selected according to type of engine and general conditions of operation. For a four-cycle engine and good conditions C may be taken from 1,000 to 1,200. For a two-cycle engine and good conditions C may be taken from 700 to 800. According to the formula of the American Power Boat Association, $C = 1{,}000$ for four-cycle engines and 750 for two-cycle engines.

We may illustrate these formulæ by the following examples:

(1) Given a two cylinder two cycle engine, cylinders 5 inches diameter by 6 inches stroke and making 560 revolutions per minute.

Then area of piston = 19.64 and

$$\text{Power} = \frac{560 \times 2 \times 19.64 \times 6}{750 \times 12} = 14.67.$$

(2) Given a three cylinder four cycle engine with cylinders as in (1) and making 900 revolutions per minute.

$$\text{Then power} = \frac{900 \times 3 \times 19.64 \times 6}{1000 \times 12} = 26.51.$$

(3) Given a six cylinder four cycle engine with cylinders 6½ inches diameter by 7 inches stroke and making 720 revolutions per minute.

Then area of piston = 33.18 and

$$\text{Power} = \frac{720 \times 6 \times 33.18 \times 7}{1000 \times 12} = 83.6.$$

PROPELLER DESIGN.

The problem of propeller design forms naturally an integral part of the general problem of speed and power; for no matter how accurately the power provided may be suited to the speed desired, the latter will fail of realization unless the boat is provided with a propeller suited to the efficient absorption and transformation of such power into the work of boat propulsion. In fact all formulæ and methods for determining the power suited to a desired speed are based on the assumption of a reasonably efficient propeller, and without such propeller all such formulæ and methods as those discussed in the preceding chapter are meaningless.

The general problem of propulsion is, if possible, more complex than that of ship resistance, and in these pages we shall not undertake any detailed consideration of this problem. It will be sufficient to note that the propulsion of a boat requires the development of a propulsive thrust sufficient to balance and overcome the resistance opposed by the water to the motion of the boat. This propulsive thrust may be viewed in two ways: (1) As the reaction resulting from the sternward acceleration of a column of water which is laid hold of by the propeller in a condition of rest and given a motion sternward or opposite to that in which it is desired to propel the boat. (2) As the resultant of the resistance which the blades of the propeller meet with in passing through the water, such resultant due to the oblique form of the blades having a forward component and constituting the propulsive thrust. The two methods are of course fundamentally the same, and represent different view points for the same phenomenon.

In no case is any complete rational theory of the screw propeller possible in the present state of our knowledge, and for practical purposes, therefore, methods must be devised in which the chief characteristics of the propeller are connected by means of empirical factors or constants with the conditions to be fulfilled.

Including a reasonably adequate analysis, the performance of a propeller may be reduced satisfactorily to its dependence on the following features:

(1) Diameter.
(2) Pitch.
(3) Revolutions.
(4) Slip at which operated.
(5) Blade area.

Of these items, numbers (1) and (2) determine between them the pitch ratio, while (2), (3) and (4) determine the speed.

Before proceeding with the discussion of actual formulæ for screw propeller design, reference must be made to the double aspect in which the term *slip* may present itself for consideration.

If we suppose a propeller of pitch p and revolutions N working in undisturbed water at a speed of advance v feet per minute, then the actual slip is $(p N - v)$ and the slip percent is $(p N - v) \div p N$. This is the so-called true slip, and is reckoned relative to the water close about the propeller and in which it is working. Now, when a boat is propelled through the water, the action of the boat on the water is to produce, as is well known, a following current or wake, most noticeable close about the stern. It is therefore in this wake or current of water which is moving forward relative to the surrounding body of still water that the propeller must work, while it is relative to the surrounding body of still water itself that speed is judged. It thus follows that the speed of the boat and the slip of the propeller are not determined from the same standard, and that the speed of the boat relative to the wake is less than that relative to surrounding still water, while the slip is correspondingly greater. The slip relative to the wake, however, must be the true slip, since it is in the wake water that the propeller is working. The decreased slip relative to the surrounding body of still water calls therefore for separate recognition and is known as the *apparent* slip.

The formula for apparent slip is thus the same as that given above for the true slip, but in this case v must be understood as referring to the speed of the boat through the still water. In any given case the difference between the two values of the actual slip is, of course, the speed of the wake or following current. In percentage of the product $p\ N$, the difference may vary widely between little or nothing for short, narrow fine lined boats with the torpedo boat or modern stern, to 20 per-cent or more for large full boats with the older form of stern. Its value is furthermore distinctly less with twin than with single screws.

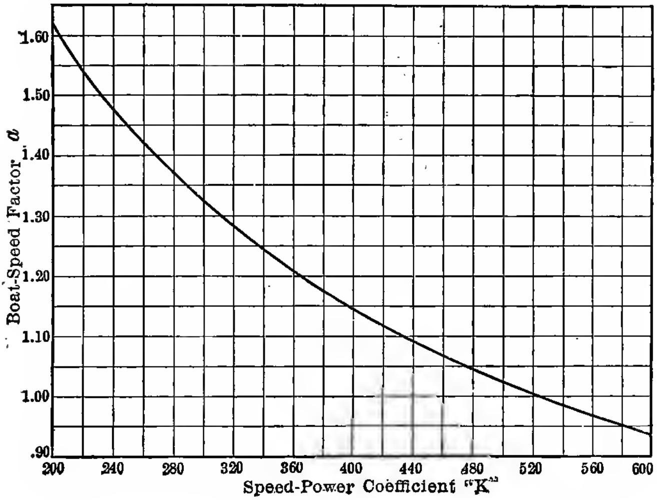


FIG. 58.

The performance of a propeller, so far as efficiency is concerned, and as an actual instrument of propulsion, must be judged, of course, relative to the water in which it is working; while so far as speed is concerned, it must be judged relative to the surrounding body of still water. In any method of propeller design providing for a recognition in detail of all the various factors which exercise a controlling influence, this double aspect of the slip must be recognized, with an estimate of the difference between the two values in any given case.

It should be understood at this point that the method of propeller design here proposed is not intended to provide in detail for the recognition of all of the factors and influences above noted, and in particular for a detailed recognition of the influence due to the wake. It is intended rather as a convenient and relatively simple method for the guidance of those who are not experts in this field, but who may wish to derive the dimensions of a propeller with some assurance of a reasonably satisfactory result.

Turning now to the development of actual formulæ and methods, we first note that in the formula for power as discussed in the preceding chapter, the relation between power and speed is made to depend on the cube of the latter. It is furthermore a fact that in all formulæ for propeller performance, no matter how disguised, the power absorbed by the propeller is also held to vary with the cube of the speed. It would therefore seem natural to expect that, by an appropriate combination of these two formulæ, we should be able to eliminate the item of power, and thus relate the dimensions of the propeller directly to those of the boat and to the other general conditions of the problem. Such a direct relation of the propeller to the boat is not unreasonable when we remember that in effect it is the resistance of the propeller which provides the propulsive thrust for overcoming the resistance of the boat. There is thus a balance between the resistance of the boat and the fore and aft component of the resistance experienced by the blades of the propeller, and under such circumstances it seems reasonable to assume that the size of the propeller may be related directly to the size of the boat, the details of the relationship being made to include the speed and such other special items of the case as the data in hand will permit.

A further reason for the convenience of a formula of this character is found in the fact that frequently the size, weight or displacement of the boat is known independently of the power or speed, and it may be desired to determine the size of propeller independent of the special question of power The problem thus becomes one of fitting to a given boat a propeller such that. whatever the power, it will be economically absorbed for propulsive purposes, and such speed realized as may properly be expected under the conditions.

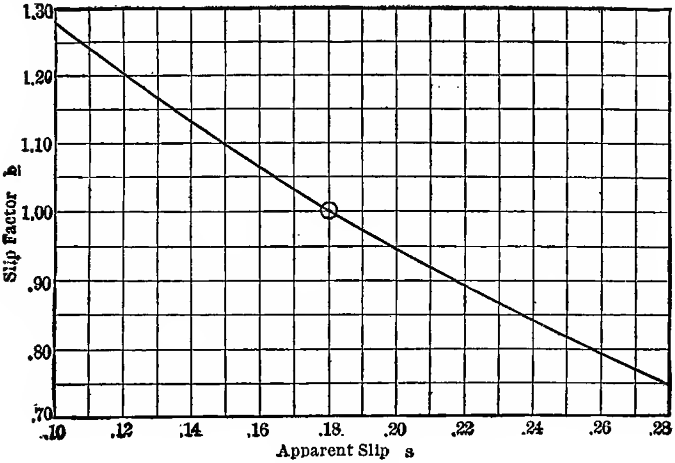


FIG. 59.

We will now proceed with a statement of the formula proposed, and its illustration by numerous examples.

Let W = weight or displacement of boat in pounds, or in case of twin or triple screws, weight divided by 2.83 or 5.2 respectively.

v = speed in miles per hour.
d = diameter of propeller in inches.
p = pitch of propeller in inches.
N = revolutions per minute.
a = boat speed factor, derived from Fig. 58.
b = slip factor, derived from Fig. 59.
c = pitch ratio factor, derived from Fig. 60.
e = area factor, derived from Fig. 61.
s = apparent slip.

Then we have:

$$d = a\ b\ c\ e\ \sqrt[3]{W} \quad \text{..........} \quad (1)$$

$$N = \frac{1056\,v}{p\ (1 - s)} \quad \text{..........} \quad (2)$$

$$s = \frac{pN - 1056v}{p\,N} \quad \text{..........} \quad (3)$$

$$p = \frac{1056\,v}{N\ (1 - s)} \quad \text{..........} \quad (4)$$

The fundamental equation (1) signifies simply that for single screw boats the diameter of the propeller in inches is equal to the cube root of the displacement or total weight in pounds multiplied by the combination factor *a b c e*, the values for which are to be derived from the special circumstances of the case. For multiple screws the operation is the same except that for *W* a certain fraction of the total weight is to be taken as noted above. The fundamental equation will thus serve to determine the diameter, and from this the pitch, revolutions and surface area will result directly from the various special assumpitons which have been made in connection with the factors *b, c, e.*

On the other hand, if the revolutions, diameter or pitch is fixed in advance, some one of the factors *b, c* or *e* will be left to be determined by the fundamental equation, and the possibility of a satisfactory solution with the assumed values will be indicated by the resulting value of such factor. These various points will be made clear by means of illustrative problems to follow.

We must first, however, discuss briefly the character of the factors *a, b, c, e.*

The boat-speed factor is intended to take account of the dimensions and form of the boat, especially in relation to the expected speed. In Fig. 58, values of this factor are plotted on

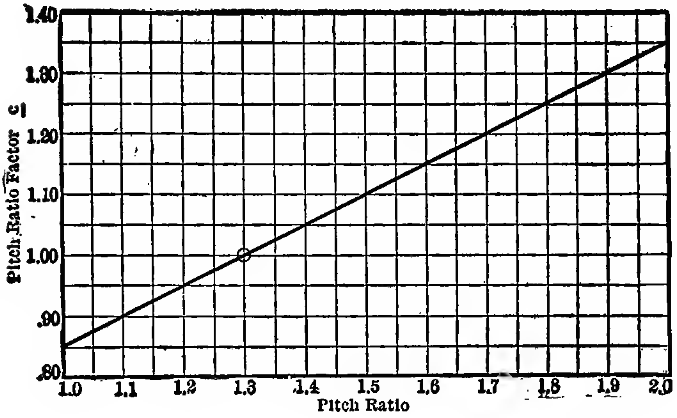


FIG. 60.

an axis of values of the Admiralty displacement or speed-power coefficient *K*, as used in the formula for powering. The values of *a* are in fact equal to $\sqrt{524 \div K}$. Reference may therefore be made to the discussion regarding suitable values of *K*, previously given in connection with the speed-power problem, and the same value of *K* used in Fig. 58 will then serve to indicate a suitable value of *a*. For reasons of numerical convenience the standard value of $a = 1$ is taken to correspond to $K = 524$. Remembering then that the usual values of *K* range from 200 or 250 to 500 or 550 it follows from Fig. 58 that the corresponding values of *a* will range from close about 1 upward to about 1.5.

The slip factor *b* is intended to provide for the increasing thrust which is obtained with increasing slip, and the consequent permissible reduction in the diameter of the propeller. The slip is one of the conditions which must usually be assumed in the solution of the problem, and the value first assumed must often be modified in order to finally reach an adjustment of the result complying with the main conditions of the problem. It will be noted that the slip used in Fig. 59 is the *apparent* and not the *true* slip. Reference may also be here made to the discussion of the difference between these two terms, which has been presented at an earlier point in connection with the speed-power problem. A strictly rational analysis of propeller action would require an estimate of the wake influence, and thus of the difference between the two values of the slip. For purposes of simplicity, however, we have assumed a standard value of the wake of ten percent of the speed of the ship, and have arranged the values in Fig. 59 on this assumption. For the purposes for which this manual is intended, the error involved in this assumption will usually be unimportant.

The pitch-ratio factor *e* is intended to take account of the fact that, other things being equal, the higher the pitch ratio the lower the thrust, and *vice versa;* with corresponding effect on the necessary diameter of the propeller. The selection of a pitch-ratio is often a matter of arbitrary choice, and the value first selected may frequently require re-adjustment, either to bring the revolutions within a suitable limit, or to make possible a satisfactory result on a specified diameter. These points will appear more clearly in connection with the illustrative problems given at a later point.

The surface-area factor *e* is intended to provide for the slowly increasing thrust with increase of area. The standard form of blade assumed is supposed to be elliptical or oval in contour, and the standard surface area is taken as .40 of the disk area of the propeller. For such area the value of the factor is 1, while for other values of the area ratio the values are as given by the diagram of Fig. 61. Detailed investigations on the influence due to area show that it depends on both pitch ratio and slip, but for simplicity the indications of the diagram are intended to apply more especially to average values of the slip, and to values of the pitch ratio close about 1.3.

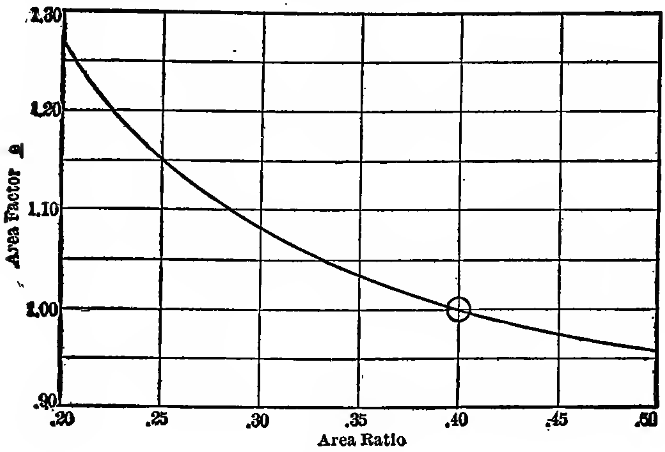


FIG. 61.

With regard to area-ratio, its usual value for propellers of two, three and four blades may be indicated as follows:

Let d = diameter of propeller.
A = total blade area.

$$\text{Then area-ratio} = A \div \left(\frac{\pi d^2}{4}\right).$$

For two blades, area-ratio is usually found between .20 and .25;
For three blades, area-ratio is usually found between .30 and .40;
For four blades, area-ratio is usually found between .35 and .50.

ILLUSTRATIVE PROBLEMS.

We shall here take, in general, the same cases used for illustration in the speed-power problems of the preceding chapter.

(1) Given $L = 36$ feet,

$W = 12{,}000$ pounds,

speed $= 9$ miles per hour,

One propeller, four blades.

Assume $K = 300$.

Then $a = 1.32$.

Take trial slip $= .18$ and pitch ratio $= 1.3$,

Then $b = 1$,

$c = 1$.

Assume standard area ratio.

Then $e = 1$.

We then have:

$$d = 1.32 \sqrt[3]{12{,}000} = 1.32 \times 22.89 = 30.21 \text{ inches.}$$

$$p = 1.3 \times 30.21 = 39.27 \text{ inches.}$$

$$N = \frac{1056 \times 9}{39.27 \times .82} = 295$$

This propeller is readily seen to have an excessively large diameter and pitch, with correspondingly low revolutions. The trial assumptions should therefore be so modified as to reduce the dimensions and increase the revolutions.

To show the influence of a single change, let us take pitch ratio $= 1.2$. Then $c = .95$ and we have:

$$d = 1.32 \times .95 \times 22.89 = 28.7.$$

$$p = 1.2 \times 28.7 = 34.44.$$

$$N = \frac{1056 \times 9}{34.44 \times .82} = 336$$

Again, let pitch ratio $= 1.1$. Then $c = .90$ and we have:

$$d = 1.32 \times .9 \times 22.89 = 27.19.$$

$$p = 1.1 \times 27.19 = 29.91.$$

$$N = \frac{1056 \times 9}{29.91 \times .82} = 387$$

Again, with pitch ratio = 1.1, let slip = .20, and we have $b = .95$, $c = .9$. This gives:

$$d = 1.32 \times .95 \times .9 \times 22.89 = 25.83.$$

$$p = 1.1 \times 25.83 = 28.41$$

$$N = \frac{1056 \times 9}{28.41 \times .80} = 418$$

Any one of these several propellers might be expected to develop the desired speed on approximately the indicated revolutions, and in general to effectively take its part in the attainment of any speed of which the conditions will permit. Still further decrease in dimensions and increase in revolutions can be made if desired. These successive steps are given to show the method of gradually approaching a combination result which shall satisfy the general requirements regarding these various features. In the remaining problems the values will be so chosen as to give immediately a more satisfactory series of values.

(2) Given $L = 33$ feet.

$W = 3600$ pounds.

Speed = 15 miles per hour.

One propeller, four blades.

Assume $K = 300$.

slip = .18.

pitch ratio = 1.4.

Then $a = 1.32$, $b = 1.00$, $c = 1.05$ and take $e = 1.00$.

Then we have:

$$d = 1.32 \times 1.05 \times \sqrt[3]{3600} = 21.25 \text{ inches.}$$

$$p = 1.4 \times 21.25 = 29.75 \text{ inches.}$$

$$N = \frac{1{,}056 \times 15}{29.75 \times .82} = 649.$$

$$A = .40 \times 353.6 = 141 \text{ square inches.}$$

Such a propeller might then be reasonably expected to develop a speed of 15 miles per hour on about 650 revolutions per minute, or any proportional speed on approximately corresponding revolutions, and in general to efficiently do its part in the attainment of any speed of which the controlling conditions will permit.

(3) Given $L = 24$ feet.
$W = 4800$ pounds.
Speed $= 7$ miles per hour.
One propeller, four blades.

Assume $K = 250$.
slip $= .20$.
pitch ratio $= 1.0$.

We then have:

$$a = 1.45$$
$$b = .95$$
$$c = .85$$
$$e = 1.00$$
$$\sqrt[3]{4800} = 16.87$$

Hence $d = 1.45 \times .95 \times .85 \times 16.87 = 19.75$ or say 20 inches

$$p = 1.0 \times 20 = 20 \text{ inches}$$

$$N = \frac{1056 \times 7}{20 \times .80} = 462$$

(4) Same as problem (3), but driven at speed of 8.5 miles, and with value K reduced to 200. Then $a = 1.62$ and with the other assumptions as before we should have:

$d = 1.62 \times .95 \times .85 \times 16.87 = 22.07$ or say 22 inches

$$p = 1.0 \times 22 = 22 \text{ inches}$$

$$N = \frac{1056 \times 8.5}{22 \times .80} = 510$$

(5) Given $L = 56$ feet
$W = 12,000$ pounds
Speed $= 25$ miles per hour
One propeller, four blades
Take $K = 350$
Suppose N fixed at 1000.

Then we proceed as follows:

Assume slip $=.18$ and pitch ratio $=1.2$, leaving e to be determined. Then:

$$p=\frac{1056\times 25}{1000\times .82}=32.2 \text{ inches}$$

$$d=32.2\div 1.2=26.83, \text{ or, say, } 27 \text{ inches.}$$

Then to test the possibility of such a propeller we substitute in formula (1) and find the resulting value of e thus:

$$27=1.22\times .95\,e\times\sqrt[3]{12{,}000}=26.53\,e$$

$$\text{or } e=27\div 26.53=1.018$$

This value of e is only slightly larger than 1.0, and denotes therefore an area ratio slightly larger than .40, or otherwise, with area ratio .40, the indications are that with the same propeller the slip would slightly increase and the revolutions rise slightly above 1000. In either case the propeller should substantially realize the conditions imposed. In case a pitch ratio greater than 1.2, such as 1.3 or 1.5, had been assumed, the resulting value of d would have been too small, and the value of e would have resulted much less than 1.00. Any such value as .8 or .9 for e thus indicates an impossible propeller, or an impossibility of fulfilling the conditions on the diameter indicated. On the other hand, should the value of e result much larger than 1, it shows that the diameter may be reduced, and still provide for the realization of the conditions imposed. A value of e slightly larger than 1.00 denotes, of course, an area ratio less than .40, in accordance with the indications of Fig. 61. In any case, where the resulting value of e does not agree with the indications of Fig. 61, changes must be made in the pitch ratio assumed, and thus by successive trials a final satisfactory combination result may be realized.

(6) We will assume the same data as in (5), but with twin screws. Then we have $12{,}000\div 2.83=4240$, and $\sqrt[3]{4240}=16.19$. Now assume a pitch ratio of 1.45, and slip $=.18$, as in (5).

Then we have:

$a = 1.22$
$b = 1.00$
$c = 1.075$
$d = 32.2 \div 1.45 = 22.2$ inches.

From formula (1):

$22.2 = 1.22 \times 1.075\ e \times 16.19 = 21.23\ e$
or $e = 22.2 \div 21.23 = 1.046.$

This value of e indicates an area ratio of .36 or .37, a value suitable for three blades, which are very commonly used for twin screw propellers.

(7) Given $L = 40$
$W = 5000$
Speed $= 28$ miles
Take $K = 500$
slip $= .18$
pitch ratio $= 1.6$
area ratio $= .40.$

Then we have:

$d = 1.025 \times 1.15 \times 17.1 = 20.15$, or say, 20 inches
$p = 1.6 \times 20 = 32$ inches

$$N = \frac{1056 \times 28}{32 \times .82} = 1127$$

(8) Given $L = 41$
$W = 3300$
Speed $= 26$ miles
Take $K = 500$
slip $= .16$
pitch ratio $= 1.9$
area ratio $= .40$

Then we have:

$d = 1.025 \times 1.06 \times 1.30 \times 14.89 = 21$ inches
$p = 21 \times 1.9 = 39.9$, say, 40 inches

$$N = \frac{1056 \times 26}{40 \times .84} = 817$$

In example (7) the values are so selected as to give a relatively small propeller with high revolutions; while in (8) the values are selected so as to give a larger diameter (though the boat is smaller) and with a marked reduction in revolutions. These two examples illustrate typical cases with extreme speeds, and indicate the wide range of flexibility of which the designer may take advantage in adapting his designs to the various special conditions of the problem.

ENDURANCE, OR RADIUS OF ACTION.

The motor boat, in common with all engineering propositions, is necessarily a compromise between conflicting and mutually exclusive requirements. In further illustration of this general law, the relation between the endurance or radius of action and the other conditions of the problem may properly receive brief notice at this point. Endurance, expressed in time, depends, of course, on the capacity of the tanks, or in general on the total amount of fuel supply, and on the demand per hour; while the distance run depends on the time and the speed. Now, supposing a fixed fuel supply, we remember that the power required, and hence the consumption of fuel, will increase as the cube, or somewhat more rapidly than the cube, of the speed. We then have the following relations expressed in algebraic form:

Let $v =$ speed,
$H =$ power,
$a =$ factor relating H to the cube of the speed, and nearly constant for any one boat,
$T =$ total fuel supply,
$F =$ amount required for a given distance,
$r =$ any given distance or radius of action,
$h =$ fuel demand per horsepower per hour,

$B =$ fuel demand per hour,
$t =$ endurance in hours.

Then $B = h \cdot H$
and $H = a\ v^3$ (nearly)
Hence $B = h\ a\ v^3$ (nearly)

$$t = \frac{T}{B} = \frac{T}{h\,a\,v^3} \text{ (nearly)}$$

$$r = t\,v = \frac{T}{h\,a\,v^2} \text{ (nearly)} \dots\dots\dots\dots (1)$$

$$F = B\,t = \frac{B\,r}{v} = h\,a\,r\,v^2 \text{ (nearly)} \dots\dots\dots\dots (2)$$

According to (1), the radius of action will decrease as the square of the rate of speed increases. That is, to double the speed will divide by 4 the distance which can be run on a given fuel supply; to increase the speed by 50 percent will divide the distance by 2.25, etc.; while on the other hand, to halve the speed would multiply the distance by 4, etc.

Likewise, equation (2) indicates that, for varying speeds, the total consumption of fuel for a given distance r will increase with the square of the speed, at least over the range for which h and a remain sensibly constant. This means that to double the speed will quadruple the fuel expense for a given distance to be run, with proportional increase or decrease in other cases.

These various relations hold approximately over a fairly wide range of speed, and indicate forcibly the excessive price which must always be paid for high speeds. Below a certain speed, of course, the boat cannot be efficiently operated at all, and at extreme low speeds the increase in the cost of power per unit, as denoted by the factor h, will begin to augment to such an extent that the cost in fuel for a given distance will begin again to increase. The point at which the fuel for a given distance is the least is known as the "most economical speed." For gasoline motor boats, such speed is usually lower than any speed at which the boat would be usually operated, and for moderate fluctuations on either side of the normal speed, the general relations as given above may be accepted as sufficiently accurate for general purposes.

These somewhat surprising results may perhaps be more clearly seen to have a rational basis, by considering that, in accordance with the indications of the formula, the consumption for a double speed will be for eight times the power, or eight times as much *per hour,* and for one-half the time, thus resulting in 8 × ½ or four times the consumption for a given distance. Similarly, for endurance or radius of action, with doubled speed, the distance will be twice as great per hour, but the fuel expense eight times as great per hour, and hence the time with a fixed amount of fuel is one-eighth. Hence we have double speed for one-eighth the time or 2 × ⅛ = one-fourth the distance.

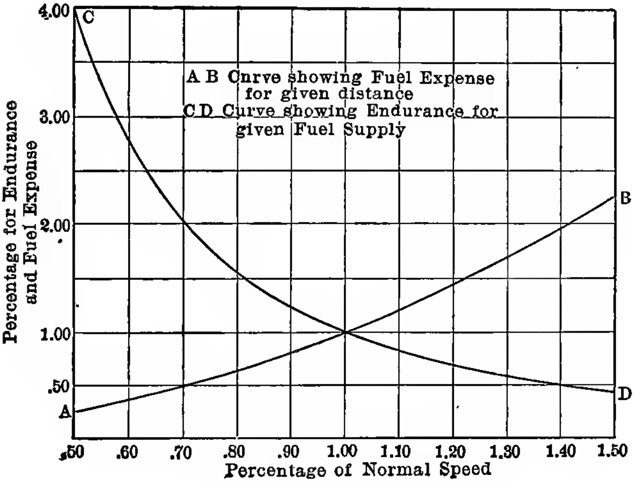


FIG. 62.

In Fig. 62 the indications of these formulæ are shown graphically for a range of speed from 50 percent of whatever may be taken as a standard or normal speed, to 50 percent above such speed.

STABILITY WHEN UNDER WAY AT HIGH SPEED.

The characteristics of the boat which favor stability have been briefly referred to under the head of design. When the boat is under way, it is readily seen that she is subject to a torque or heeling moment exactly equal to the turning moment of the engine. This follows from the general fact that action and reaction are equal in amount and opposite in direction, and hence that if the engine tends to turn the shaft in its bearings carried on the boat as a foundation, so is there an equal tendency to turn the boat about the shaft as an axis or spindle, and in the direction opposite to that of shaft rotation. This turning or heeling moment in motor boats at high speed may be sufficient to represent the equivalent of several hundred pounds placed on the gunwale, and the result may well be a decided list in the direction opposite to that in which the propeller is turning. To compute the weight on the gunwale, equivalent to the turning moment of the engine, we may proceed as follows:

Let H = power developed by engine,
N = revolutions per minute,
M = turning moment,
B = beam of boat in feet,
W = equivalent weight at gunwale in pounds.

Then $M = \frac{33{,}000\,H}{2\,\pi\,N} = \frac{B\,W}{2}$

or $W = \frac{33{,}000\,H}{\pi\,B\,N}$

Thus, for illustration, let $H = 120$, $N = 800$ and $B = 5$.
Then $W = (33{,}000 \times 120) \div (3.1416 \times 5 \times 800) = 317$ pounds.

Such a heeling moment may enter as a serious factor into the question of stability, and may reduce to an uncomfortably low margin what might be otherwise a reasonably abundant provision. The result may be to render such boats in a seaway uncomfortably cranky, and for specially high speeds the question of a large margin of stability is one which should receive due consideration. If the torque were uniform in value, it might be possible to counterbalance its influence by setting the machinery off the center line on the side toward which the crank turns when passing its top center. Unfortunately, however, the torque varies with the power, and such an arrangement would leave the boat on an uneven keel when at rest or under low speed. It may at least be remembered, however, that the boat will tend to heel opposite to the direction of the rotation of the propeller, and shifting ballast may be provided, or, if there is any tendency toward inequality in the disposition of the weights of the machinery and equipment, the over balance should be so adjusted as to counterbalance as far as may be the effect of the turning moment; that is, the excess weight should come on the side toward which the crank turns when passing the top center.

REACTION OF PROPELLER ON RUDDER.

The somewhat irregular action of the blades of the screw propeller working in the disturbed water about the stern of the boat tends to develop a force deviating the boat from her course. To control this deviation in the case of small, high-speed boats, extra-large rudder area should be provided. This deviating force due to the propeller is the result of several components, some of them opposite in character, and the resultant itself may partake of the character of one component or the other, depending on which influence is paramount.

So far as the following wake is concerned its value is the largest near the surface, and it will thus give rise to an increased value of the slip while the blade is on its upper quadrant, and with a right hand propeller it is seen that this would develop a force tending to throw the stern to port. On the other hand, in small, high-speed boats in particular, the propeller blades are likely to be near the surface of the water while on their upper quadrant, and working in water less solid or continuous than for the lower blades. So far as this condition may affect the result, the extra resistance to the motion of the blades will be while on their lower quadrant, and this will develop a force tending, with right hand rotation, to throw the stern to starboard.

With large ships having the conventional form of stern, the former influence as a rule will predominate, and the stern will swing to port with a right hand propeller, while with small boats with the torpedo boat stern, the wake is less pronounced, and the latter influence is the more likely to predominate, throwing the stern to starboard with a right hand propeller. In any case, the provision of rudder area should be generous, and experience will soon indicate the position of the helm for a steady course.

TROUBLES, AND HOW TO LOOK FOR THEM.

The number of ways in which a gasoline engine may fail to operate properly, and the number of causes which may contribute to trouble, are legion, and within present limitations only some general principles can be given as an aid in locating trouble when it arises. The location of trouble in the operation of a gasoline engine is exactly a process of diagnosis, and this again is a process of analysis and isolation. The operation, as a whole, must be resolved into its various parts or functions, and one item after another of the mechanism and equipment must be examined, in order to gradually isolate, and thus by a process of exhaustion ultimately locate, the seat of the trouble.

The operation of a gasoline engine, aside from the mechanism itself, demands the simultaneous realization of two chief functions or conditions·

(1) An electric spark of sufficient intensity to ignite a proper mixture of gasoline vapor and air compressed to a point suitable for such ignition, and occurring at or near the end of the compression stroke.

(2) The provision of a charge of gasoline vapor mixed with a suitable proportion of air and compressed at the end of the stroke to a pressure suitable for ignition.

These two main conditions, one referring to the electrical spark and the other to the charge of gasoline, are, of course, quite independent, and may be taken up each in turn, and in either order, until the trouble is located.

In the absence of specific indications, as referred to later, the point of most direct attack is usually the existence or non-existence of a spark. This can generally be ascertained by such observations as will readily present themselves to mind. If a full and adequate spark is formed, then attention must next be given to the question as to whether it is formed at the right point in the stroke. It is perfectly possible for a commutator to become disturbed in adjustment, or for other derangement to displace the instant of forming the spark relative to the piston position, to such an extent as to render it of no avail for the ignition of the charge. In short, here, as at all other points, care must be taken to insure the complete fulfilment of all items of the electrical condition—not alone the existence of a vigorous spark, but one so located as to come at or near the end of the compression stroke, and thus available for the ignition of the charge. If no spark whatever is formed, or if it is feeble or uncertain, then there is trouble somewhere on the electrical side, and the problem becomes one of further localisation.

We must remember that electrical energy operates in closed circuits, and that a break or disturbance at any point in such a circuit may prevent its performing its proper function. In the wipe contact system of ignition there is one such circuit, in the jump spark, two. In a search of this character we may either start from the batteries as the fountain head, and follow down to the ignition plug or wiper terminals, or we may proceed in the inverse direction. Usually the former is the more satisfactory and definite in results. Thus, place a voltmeter or ammeter across the terminals of the battery, or in the absence of such instruments, watch for a spark when shortcircuited and broken by a bit of wire, or better still by a small magnet coil. The spark, or its absence, will show whether the battery is in good condition. If not, a broken or poor contact may be found at some of the terminals or connections between the cells. It may even be necessary to test out each cell separately, thus giving definite assurance in the end that the battery is or is not at fault.

If the battery is all right, and the wipe spark is used, then the instrument or short circuiting coil applied along at one or two intermediate points will serve to bring the problem down to the engine, and if the search has been properly carried out, the trouble will surely be found by the time we reach the wiper terminals in the cylinder. In general, electrical trouble must be looked for at junctions and connections, and at the terminals in the cylinder. The conditions for good electrical conductivity are simple—continuous connection and good firm contact between bright metallic surfaces; and search should be especially directed to see if these conditions are fulfilled.

If the jump spark system is used, the same principles apply, but we may find troubles differing in detail. Thus, the vibrator or make and break of the primary circuit may be out of order, and thus fail to operate with its accustomed buzz. If the primary current itself is all right, then trouble at the vibrator is of a mechanical nature, and is usually a matter of adjustment of the armature and controlling springs. Cases have been known where, with a relatively weak spring, the rate of vibration of the armature was too slow for the higher speeds of the engine, while quite sufficient for low speeds. In consequence, the engine would operate quite satisfactorily at low speeds, but would begin to miss fire and operate irregularly at the higher speeds. A stiffer spring with proper adjustment and suitable battery power is the remedy indicated.

Again, within the cylinder, the sparking points may become separated too far, or incrusted with non-conducting substance to such degree as to impede or interrupt the passage of the secondary spark. In any and all cases the same general principles apply. It is simply a matter of careful search at one point after another, conducted in an orderly manner, and in such routine as to gradually eliminate one possibility after another, until finally, by a process of exclusion, the difficulty must be located.

If the first direct test at the terminals of the electrical circuit indicates no trouble of an electrical character, then the location of the trouble must be sought in the other general condition, that relating to the explosive charge. Here the general conditions to be fulfilled may be classified under perhaps four headings, as follows:

(1) The supply of gasoline must be ample, but not in excess.

(2) It must be vaporized, and mixed with a proper proportion of air.

(3) It must be compressed to a pressure suitable for ignition.

(4) Waste gases or foreign substances, such as cylinder oil, carbon deposit, etc., must not be present, beyond a safe small amount.

In the search for trouble, all of these conditions must be borne in mind, and by the same general policy of exclusion the trouble must ultimately be located. Trouble with the supply of gasoline may arise in a variety of ways. The supply in the tank may be exhausted; the air relief valve or opening may be closed; some valve or turn or pipe may be clogged with sediment or foreign matter; some connection or pipe may be broken, and the supply thus interrupted by leakage; the carbureter may be out of order by clogging or by lack of adjustment; the opening of the gasoline throttle may be too great or too little, either flooding the cylinder with an excess or furnishing an inadequate supply.

Again, trouble in vaporization or with the proportion of air may be due to faulty construction of the carbureter or to faulty adjustment, especially with reference to the air supply.

Failure to secure proper compression may be due to a leaky piston, or, in the case of a four-cycle engine, to leaky valves, either supply or exhaust, allowing the compressed vapor to escape instead of retaining it in the cylinder to the proper point of compression.

The quality of the charge may be injuriously affected by the presence of waste gases in too great proportion, or by cylinder oil or carbon in undue amount. The presence of these latter may be prejudicial, not primarily because of their effect on the explosive character of the charge itself, but rather, as previously noted, because they are liable to clog the sparking points, and require an electrical pressure greater than the battery can afford in order to make an effective spark.

Troubles of a mechanical character may also arise in great number, but to these we shall give no present attention beyond the general caution that all bearings, pin joints and connections must be carefully watched for wear, proper lubrication must be insured, and in particular the condition of the piston and inner surfaces of the cylinder must be safeguarded by sufficient but not by an excess of cylinder oil, and by an adequate and continuous supply of cooling water.

SYMPTOMS OF TROUBLE.

As with diseases in the human body, the same symptom may often be due to widely different causes. Still, an intelligent and critical examination of the symptoms will often give valuable indications regarding the cause of the trouble, and in any event, before any general hunt for the location of trouble, a careful study of the symptoms should be made. Some of the more common symptoms are noted below, with the possible indications to which they may refer.

(1) *The explosions cease suddenly* and without warning, bringing the engine from full power to a sudden stop. The trouble here is probably electrical, and the symptoms imply a sudden break in the electrical circuit or derangement in the electrical apparatus, cutting off the spark suddenly and completely

(2) *The explosions miss occasionally* and with varying frequency. This condition may be due to a variety of causes. The battery may be losing its strength, or there may be a vibrating contact. By the latter is meant a point where the copper of a wire is broken, but the ends are so held by the insulation, or otherwise, as to remain nearly in contact, and by the vibration due to running they may be occasionally brought into contact and thus allow the spark to form; or if normally in contact the vibration may occasionally separate the ends, in either case producing an irregular operation in accordance with the formation of the spark.

The same symptoms may also be due to fouling of the spark points, to fouling of the commutator with oil or foreign matter, to trouble with the vibrator, to improper quality of the explosive charge, to insufficient compression, or, in fact, to a derangement in almost any one of the many conditions which must be simultaneously fulfilled, and in such manner as to permit an uninterrupted fulfilment of such conditions.

(3) *Weak explosions.*—This symptom may be due to improper quality of the explosive charge, due to derangement of the carbureter, or to any other derangement which may interfere with the quality of the charge; also to insufficient compression, and consequently incomplete or retarded combustion; also to the formation of the spark at the wrong point in the piston stroke. The size and character of the spark have also some influence on the strength of the explosion. This, as well as the preceding symptom, may thus be due to a wide range of causes.

(4) *The engine slows down or stops,* and examination shows that the cylinder is excessively hot, and that the piston moves very stiffly in the cylinder. These general symptoms indicate insufficient lubrication or cooling or both, and the sticking of the piston within the cylinder.

(5) *The explosions gradually become weaker* and the engine finally comes to rest. This result may be due to any continuous and perhaps rapid development of conditions which may serve to disturb the operation of the machine, and perhaps bring it to a standstill. The supply of gasoline may first be examined, and if adequate the most probable location of the trouble will be in the electrical circuit somewhere, and presumably in the batteries.

(6) *Muffler Explosions.*—An explosion in the muffler is due to the passage of unburned gas from the cylinder through the exhaust into the muffler. This usually implies faulty ignition, in which case an entire charge may pass into the muffler and become ignited by the hot gases from the following exhaust stroke, or by a bit of glowing carbon or otherwise. The cause of the faulty ignition may, of course, be traceable either to the quality of the charge or to the spark, or both, and the search for final causes must be sufficiently comprehensive to cover all possibilities bearing on these conditions.

(7) *Crank Case Explosions.*—These occur only in a two-cycle engine, and are due either to delayed ignition, or to a weak and

slow burning mixture. In such case there is a possibility of the passage of flame from the cylinder into the crank case along the line of the entering fresh charge. The obvious remedy is to advance the spark, or to attend to the quality of the mixture.

The more common derangements may also be mentioned, together with a statement of the usual immediate consequences.

(1) *Ignition very late.*—Difficulty in getting explosions, and if obtained, the power developed is small and operation irregular. Liability to crank case explosions with two-cycle engines. The condition may also contribute to cause muffler explosions.

(2) *Ignition very early.*—Difficulty in getting explosions, or if obtained, the piston is momentarily retarded, excessive stresses are thrown on the working parts, and the operation of the engine is irregular and jerky.

(3) *Vibrator spring too weak.*—Engine will operate properly at moderate speeds, but ignition will become irregular as the speed is increased.

(4) *Poor electrical contact or break at any point in circuit.*—Uncertain spark or no spark and corresponding explosions.

(5) *Stoppage in gasoline pipe or connections.*—Engine slows down and stops.

(6) *Carbureter improperly adjusted.*—Quality of mixture bad, and engine will operate irregularly or not at all, or well at some speeds and poorly at others.

(7) *Exhaust valve not tight or spring too weak.*—Inflow of air with explosive charge, and disturbance in quality of mixture. Likewise, escape of mixture under compression and difficulty in obtaining proper pressure for ignition.

(8) *Inlet valve not tight.*—Escape of mixture under compression, and difficulty in obtaining proper pressure for ignition.

(9) *Piston leaky.*—Same general result as for leaky valves.

(10) *Excess of gasoline.*—Quality of mixture too rich. Difficulty in ignition or in starting engine. Smoke may show in exhaust—usually black in color.

(11) *Excess of lubricating oil.*—Spark points become fouled by solid carbon or viscid mixture, with uncertain or difficult ignition. Smoke shows in exhaust—usually light gray in color. Presence of carbon may cause preignition, kicking, or back firing into crank case or carbureter.

With reference to the entire problem of trouble hunting, it should be understood that the ability to quickly locate and to properly treat such troubles as are liable to arise in the operation of a gasoline engine cannot be acquired by any mere study of symptoms and causes or derangements and results. The study must be fundamental rather than symptomatic, and must have for its purpose the thorough understanding of the conditions of operation of a gasoline engine, and the development of an analytical habit of mind with reference to the logical connection between such symptoms as may appear, and the conditions of operation. With such habit of mind and a careful examination by the method of exclusion, the trouble may be surely and definitely located, and the remedy applied.

RACING RULES AND TIME ALLOWANCE.

The fundamental purpose of time allowance, based on rules for the classification of racing boats, is to eliminate such advantages as may belong to mere size or power alone, and to make possible a contest on reasonably even terms among boats of different sizes and powers. It will be remembered, from the chapter on power, that in general the larger the boat the more easily is a given speed realized. Especially is this the case with reference to the influence of increasing length. It will result in consequence that large boats, and in particular boats in which the length is exceptionally great in relation to the size, will thereby possess an advantage by such fact alone, and no contest on reasonably even terms could be held between such a boat and one markedly smaller, or with a much smaller proportion of length to general size. Again, it is generally agreed that the advantage given by horsepower alone should be eliminated from speed contests, so that among boats, for example, of the same size and of similar forms, differences in the power should not enter as a determining factor in a racing contest.

From the reverse point of view, it may be said that in speed contests every item of difference between the contestants should be eliminated except the following:

(1) Consistency and general excellence of design.

(2) Integrity and general excellence of construction.

(3) Skill in handling and in making the most of the boat as actually designed and built.

Still otherwise we may ask regarding each contestant the following question:

With the boat as it is, and assuming a thoroughly consistent and carefully studied design throughout, together with integrity and general excellence of construction and a good degree of skill in handling, what speed may be reasonably expected? If this question can be answered, then such speed will determine the rating, and the differences in such speeds will determine the time allowances for the various boats. Such allowances or corrections being applied, it will result that all differences in speed will be eliminated, except such as may depend on items (1), (2) and (3) above noted; and to the boat which excels in the combination of these three items will go the honor of victory.

It may thus result that a boat making the course at a speed of 18 knots, for example, may be beaten by another making only 16. This will mean that the latter, with reference to these items (1), (2), (3), was the better boat, and showed the better performance of the two. Of course, nothing can change the actual relative speeds of the two boats, and the owner of the faster boat has always the satisfaction of the higher actual achievement, with the possibilities for use or pleasure which such achievement may imply. These considerations are unaffected by racing rules, and remain as some offset to the possibility of the race not going to the actually faster boat.

Again, there has always been a feeling that racing rules should be so devised as to discourage the building of freaks, or of boats intended simply to gain all possible advantage from the character of the particular rule or formula for rating, and independent of the real value of the resulting boat. Rather, if possible, the rule should be so drawn as to favor the development of staunch and serviceable boats, and with the most carefully studied combination of useful features.

The general problem of time allowance involves then two distinct elements or parts:

(*a*) The determination of the speed which may properly be expected from a boat of reasonably normal and useful proportions and characteristics, and of specified size and horsepower.

(*b*) The framing of the formula in such manner that to the desired extent boats which depart widely from normal proportions and serviceable combinations shall be placed at some relative disadvantage with reference to the rule.

The first, or (*a*), states the broad problem for the normal boat. The second, or (*b*), is intended to discourage the production of freaks and racing machines. Now, referring again to the chapter on speed and power, it will be clear that the speed depends primarily on three things:

(1) The power developed by the engine and delivered to the shaft.

(2) The power utilized by the propeller and applied to the propulsion of the boat.

(3) The resistance due to the size and form of the boat.

We will consider these in order.

The power of an internal combustion motor depends on the following items:

(1) The number of cylinders, denoted by n.

(2) The area of piston denoted by A.

(3) The length of stroke, denoted by L.

(4) The mean effective pressure, denoted by p.

(5) The number of revolutions per minute, denoted by N.

(6) The character of the cycle, represented by a factor f.

Expressed as a formula we have then:

$$H = \frac{p\ L\ n\ A\ N}{33{,}000\ f} \quad \text{(1)}$$

Now, in comparing one engine with another, the factors L, n, A, f are matters of direct observation or measurement, and their values are readily determined. There remain N and p for further consideration.

Regarding revolutions N, we find in actual practice values all the way from 500 per minute or below to 1,000 or above; and, of course, this factor is not observable or measureable before the race, as in the case of L, n, A, and f. For comparing one engine with another it may be more convenient or useful to use the product $2N\ L$, or piston speed, rather than the revolutions N alone. Remembering then that for the internal combustion engine as used in typical motor boats the length L will usually be found from 6 to 9 inches, or 0.50 to 0.75 foot, it is clear that values of the piston speed will range from 500 up to 1,000 or above. In accordance with the fundamental nature of time allowance we should then ask—what is the value of the revolutions or piston speed corresponding to a thoroughly consistent, carefully developed design, in which reasonably full advantage has been taken of all engineering possibilities which bear upon such problems? This presupposes a well constructed engine, designed carefully throughout, and with special reference to the highest speed of rotation or piston speed consistent with the other features of the design; and combined with a propeller so designed as to permit the attainment of the designed rotative speed, and which will under such conditions efficiently transform the power of the engine into useful work of propulsion. The fact that rotative speed depends on the adaptation of propeller to boat, and, of course, on the provision of adequate power in the engine itself, should be kept clearly in mind in connection with these various relations.

Unfortunately there is no definite answer to the question outlined above. Opinions will vary, circumstances and special purposes will justify variations in the matter of speed of rotation or piston speed, and furthermore, the two types of engine—two-cycle and four-cycle—are not quite similarly situated with reference to the development of high speed. It should be noted in passing that if each designer and builder is frankly aiming at the highest rotative or piston speed which he can make effective, and all engines are of the same form of cycle, then the exact figure which may be taken as the standard is of less importance. The relative positions of a series of such boats will be the same, no matter with what standard they may be compared, and while the relative allowances will vary slightly with the standard adopted, such variation would, as a rule, be of no serious importance.

Thus, if all boats had four-cycle engines, and 800 revolutions were taken as the standard value for rotative speed, then each engine would be rated as for such speed. If the designer cannot attain it, he must suffer in diminished speed, and if he exceeds it, he gets the benefit in increased speed. With actual boats, however, there are designs for which (say) 600 revolutions may seem a proper limit, and in which the designer makes no pretense of striving to attain a higher speed. The design is consistent and carefully developed, with reference to this speed. In another design a distinct effort to realize high rotative or piston speed is made with reference to a high boat speed, and, for example, 1,000 revolutions are easily obtained. If then these two boats with different aims are both rated for power on the basis of 800 revolutions, obviously the latter will have a very marked advantage. Differences of this character cannot be properly evaluated in any scheme of rating, and any and all methods and formulas are unsatisfactory for the rating of boats in which the primary purposes of the design have not been the same.

Again, the limitations of the two-cycle and four-cycle types with regard to rotative speed are not the same, and it is therefore doubly hard to fairly relate engines of the two-cycle type with those of the four-cycle type. The two-cycle engine has large passages for the flow of vapor or gas in and out of the cylinder, but at high rotative speeds, that is, with a high number of changes per minute, it is difficult to keep the inflow and outflow separate and to realize an explosive charge in a reasonably high degree of purity. On the other hand, with the four-cycle engine, the valve openings and passages are naturally smaller, but relatively more time is given for the inflow and exhaust events. In a general way it results that the limitations in the case of the two-cycle engine are primarily dependent on the rapidity of the changes, or on the revolutions; while in the case of the four-cycle they are dependent on piston speed. High rotative and piston speeds may be and are realized with both types of engines, but it will presumably be admitted that high rotative speed in the four-cycle engine will result in a less marked falling off in the value of the mean effective pressure than in the case of the two-cycle.

To sum up with regard to rotative and piston speeds, we conclude that:

(1) The rating of engines, all with reference to the same standard revolutions or piston speed, can be fair only when all engines so rated are designed primarily for the same general purpose. Any attempt at classification will, of course, involve some vagueness of definition or interpretation, but unless there is some reasonable similarity of purpose in the designs, it is hopeless to expect any rating rule to properly relate the boats for purposes of racing.

(2) Within a class restricted to boats designed all for the

same general purpose, and all with engines working on the same cycle, the exact value of the revolutions or piston speed adopted as a standard is of relatively less importance.

(3) Between engines working on the two-cycle system and those on the four-cycle, no rule can be entirely satisfactory, and any rule adopted will be sure to bear unequally in accordance with the special characteristics of the case.

Turning now to mean effective pressure, p, and referring to the earlier chapters on the engine, we find ground for the conclusion that with the same general conditions otherwise, this factor will be less for the two-cycle than for the four-cycle. The value of p depends primarily on the purity of the mixture, and in this respect the four-cycle type scores a marked advantage, especially at high rotative speeds. We shall here assume that with equally good practice in each type of engine, the value of p in the two-cycle engine should be 80 percent of that in the four-cycle. This will give the relation,

$$p_2 = 0.80\, p_4$$

Turning now to the horsepower formula above, we have:

$$H = \frac{p\,L\,n\,A\,N}{33{,}000\,f} = \frac{p\,n\,A \times 2\,LN}{33{,}000 \times 2\,f}$$

Then, putting for $2L\,N$, the piston speed, the single letter S, we have:

$$H = \frac{p\,n\,A\,S}{66{,}000\,f} \qquad \text{(2)}$$

where $f = 1$ for two-cycle and 2 for four-cycle engines.

Then, with the above understanding regarding the relation between p for two-cycle and four-cycle engines, and denoting the values in each case by the subscript 2 or 4, we have:

$$\frac{H_2}{H_4} = \frac{2\,p_2\,n_2\,A_2\,S_2}{p_4\,n_4\,A_4\,S_4} = \frac{1.6\,n_2 A_2 S_2}{n_4\,A_4\,S_4} \qquad \text{(3)}$$

Regarding the proper value of the ratio of S_2 to S_4, there is little direct information, and any value must in effect depend largely on general opinion as to the operation of the limitations on revolutions and piston speed in the two cases. With the ratio p_2 to p_4 of 0.80, which we have already assumed, we shall take as a corresponding ratio of S_2 to S_4, about 0.78, giving:

$$\frac{H_2}{H_4} = 1.25 \frac{n_2 A_2}{n_4 A_4} \quad \text{.......................................} \quad (4)$$

Then, taking two general classes of boat—high speed and moderate speed—and the two types of engine, we have as follows:

(1) For all craft built expressly for high speed, and with four-cycle engines, we assume

$$p = 66$$
$$S = 1{,}000$$

This gives:

$$H = \frac{66\,n\,A \times 1{,}000}{132{,}000} = \frac{n\,A}{2}$$

(2) For all craft as in (1), but with two-cycle engines we shall then have:

$$H = \frac{1.25 \times n\,A}{2} = \frac{n\,A}{1.6}$$

(3) For all other craft in a single class, and with four-cycle engines, we may assume a standard value of $S = 666$. Then:

$$H = \frac{66\,n\,A \times 666}{132{,}000} = \frac{n\,A}{3}$$

(4) For all craft as in (3), but with two-cycle engines, we may properly assume the relative power as slightly greater than for the high speed class. We shall therefore take

$$H = \frac{1.3 \times n\,A}{3} = \frac{n\,A}{2.3}$$

In general we may put:

$$H = \frac{n\,A}{B} \quad \text{.......................................} \quad (5)$$

where H = horsepower.

n = number of cylinders.

A = area of piston.

B = factor, as below.

Values of B:

High speed, four-cycle, $B = 2$.
High speed, two-cycle, $B = 1.6$
Moderate speed, four-cycle, $B = 3$
Moderate speed, two-cycle, $B = 2.3$.

It is, of course, impossible to satisfactorily draw the line between so-called high and moderate speed. Each class shades into the other by imperceptible gradations, and any attempt, as above, to specify two classes, must be crude and unsatisfactory, and produce results on the time allowance value which cannot be considered entirely fair. On the other hand, the inclusion of all engines into one class with reference to piston speed will be no less unsatisfactory and unfair, and between the two possibilities it has seemed best to suggest, in accordance with the practice of the American Power Boat Association, the two classes as above.

TIME ALLOWANCE.

Let v_0 = speed of standard boat in knots.
v_1 = speed of any other boat, assumed as less than v_0.

Then $1 \div v_0$ and $1 \div v_1$ represent respectively the time in which each boat will go one nautical mile, and the difference between these times, reduced to seconds, will be the time allowance per mile.

Denoting this allowance by a we have then:

$$a = 3{,}600\left(\frac{1}{v_1} - \frac{1}{v_0}\right) \quad \text{(6)}$$

This amount is thus the difference in time which may be expected between the two boats in one mile, and this allowance being applied, it is assumed to bring the boats to an equal footing as regards the items properly entering into a racing contest, and to determine as the victor the boat showing the least time after correcting the actual time by this amount per mile.

In order to determine the value of this allowance, therefore, we must determine the speed which may be fairly expected. This requires the application of some form of speed-power formula. There are many such, no one of which is more than a crude approximation to the conditions which it is desired to fulfil. The more important of these are as follows:

(1) The formula should provide for the rapidly increasing demand for power as the speed increases, the boat remaining the same.

(2) It should provide for the more slowly increasing demand for power as the boat increases in size, the speed remaining the same.

(3) It should satisfy the extended law of comparison, as a result of which boats of similar form at speeds related as the square roots of their lengths will require power in the ratio of the 7/2 power of the lengths.

The common so-called Admiralty formulæ:

$$H = \frac{(\text{Midship section area}) \times v^3}{\text{Constant}} \quad \dots\dots\dots\dots\dots\dots (7)$$

$$\text{and } H = \frac{D^{\frac{2}{3}} \times v^3}{\text{Constant}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (8)$$

fulfil the last condition, but neither of the others in altogether satisfactory degree. The index for the speed v should, as a rule, be more than 3, while perhaps 4 is too high, especially where the design is such as to cause the boat to rise partially out of the water at very high speeds. Again, for boats of increasing size at the same speed, the variation as the midship section area, or as $D^{\frac{2}{3}}$, is too rapid for the power, and if correct for the small boat would determine an excess for the large boat. This latter fault may be compensated for in a measure by introducing a size or dimension factor in the denominator. If this be taken as the square root of the length, denoted by $\sqrt{L}$, we may put the formulæ above in the form:

$$H = \frac{(\text{Midship section area}) \times v^3}{B_1 \times \sqrt{L}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$\text{and } H = \frac{D^{\frac{2}{3}} \times v^3}{B_2 \times \sqrt{L}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

In this form the third condition is no longer fulfilled, while the first still remains as before. It is, however, entirely possible to develop formulæ which will, in more or less satisfactory degree, fulfil these various conditions, but at the expense of simplicity of form. Thus, take the formula:

$$H = \frac{D^{\frac{3}{4}} \times v^{\frac{7}{2}}}{B \times L^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

This provides for the variation of the power more rapidly than as the cube of the speed, and fulfils the other conditions (2) in reasonable degree and (3) exactly. The use of such a formula as a basis for time allowance would, however, lead to unwieldy roots and powers, and, having in view the crude and somewhat arbitrary character of time allowance at the best, it is doubtful if the apparent gain would be worth the added labor and difficulty of application. In any event, we shall here assume that it would not, and shall therefore recur to the simpler formulæ (9) and (10) above. The choice between these two turns on the relative usefulness of the midship section area and the two-thirds power of the displacement as a factor in such formulæ. We shall prefer the latter, briefly for the following reasons:

(1) It is presumably more consistently related to the power than is the midship section area, and as a function of volume takes more accurate account of variations in form than is possible for an area such as the midship section.

(2) By the use of the displacement rather than the midship section area it is more difficult to design a boat with reference to gaining a special advantage from the form of the rule.

Adopting, therefore, the formula (10), and writing the factor B without subscript, we have as follows:

$$H = \frac{D^{\frac{2}{3}} \times v^{3}}{B \times L^{\frac{1}{2}}} \quad \text{(12)}$$

$$v = \frac{B^{\frac{1}{3}} \times H^{\frac{1}{3}} \times L^{1}}{D^{\frac{2}{9}}} \quad \text{(13)}$$

$$B^{\frac{1}{3}} = \frac{v \times D^{\frac{2}{9}}}{H^{\frac{1}{3}} \times L^{\frac{1}{6}}} \quad \text{(14)}$$

Now, applying these values in the formula for time allowance above, we have:

$$a = \frac{3{,}600}{B^{\frac{1}{3}}}\left(\frac{1}{\frac{H_1^{\frac{1}{3}} \times L_1^{\frac{1}{6}}}{D_1^{\frac{2}{9}}}} - \frac{1}{\frac{H_0^{\frac{1}{3}} \times L_0^{\frac{1}{6}}}{D_0^{\frac{2}{9}}}}\right) \quad \text{(15)}$$

Next, applying (12) to a series of trial results, and using for D the weight W in pounds, we find as a good average value $B = 4{,}096$ and $B^{\frac{1}{3}} = 16$. We must next arbitrarily assume a speed for the so-called standard boat. This we shall take as 24 knots. Then from (13) we have, writing W instead of D:

$$\frac{H_0^{\frac{1}{3}} \times L_0^{\frac{1}{6}}}{W_0^{\frac{2}{9}}} = \frac{24}{16} = 1.5 \quad \text{(16)}$$

Substituting these numerical values in (15), and multiplying both numerator and denominator by 66.˙6, we have:

$$a = \frac{3{,}600}{16}\left(\frac{66.\dot{6}}{\frac{66\dot{6}\, H_1^{\frac{1}{3}} \times L_1^{\frac{1}{6}}}{W_1^{\frac{2}{9}}}} - \frac{66.\dot{6}}{100}\right) \quad \text{(17)}$$

$$\text{or } a = 15{,}000\left(\frac{1}{\frac{66.\dot{6}\, H_1^{\frac{1}{3}} \times L_1^{\frac{1}{6}}}{W_1^{\frac{2}{9}}}} - \frac{1}{100}\right) \quad \text{(18)}$$

Now the quantity $\frac{66.\dot{6}\, H_1^{\frac{1}{3}} \times L_1^{\frac{1}{6}}}{W_1^{\frac{2}{9}}} = \frac{200\, H_1^{\frac{1}{3}} \times L_1^{\frac{1}{6}}}{3\, W_1^{\frac{2}{9}}}$ we shall call the rating, and denote it by the single letter R.

We have, then, in general, for any boat:

$$\text{Rating} = R = \frac{200\, H^{\frac{1}{3}} \times L^{\frac{1}{6}}}{3\, W^{\frac{2}{9}}} \quad \text{(19)}$$

The multiplication by 66.˙6 or by 200 ÷ 3 in (17), and in the formula for rating, (19), is simply to bring the rating of the standard boat to the figure 100. Then for (18) we have:

$$a = 150\left(\frac{100}{R} - 1\right) \quad \text{(20)}$$

If, in any case the rating R should be greater than 100, the value of a would be negative or subtractive, and for its numerical value we should have:

$$a' = 150\left(1 - \frac{100}{R}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

Now the values of the time allowance in the tables, given for example in the hand book of the American Power Boat Association, are simply the values of a and a' computed from the above formulæ for the various values of the rating R. The fact that we have thus reproduced the table of allowances as given in this hand book means simply that the standard rating is taken arbitrarily at 100, and the standard speed at 24, and any time allowance table based on these standards will have values as given by the equations (20) and (21) above, quite independent of the particular formula from which the rating is derived.

Another point of interest in connection with the rating is readily derived by substituting from (19) into (13). We thus find:

$$v = \frac{3\,B^{\frac{1}{3}} \times R}{200} = 0.24\,R \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

That is, the speed by formula, or the reasonably expected speed, is 24 percent of the rating as found by rule. It is not uncommonly supposed that the rating is a sort of length, or that it has something to do with length. This is entirely erroneous, and as shown above, it is directly related to speed by the relation shown in (22). Hence we readily see that for any boat of rating R, the reasonably expected speed is simply 24 percent of such rating.

With regard to the value of the rating as given in (19), it will be desirable to express this in other forms, as follows:

$$R = \frac{200\sqrt[2]{H\sqrt{L}}}{3\sqrt[3]{\sqrt[3]{W^2}}}$$

or:

Rating equals 200 times the cube root of the power, multiplied by the sixth root of the length in feet, and divided by 3 times the two-ninths power of the weight in pounds. Again, to find the two-ninths power we have the simple

Rule: Take the cube root of the cube root, and square the result: or, take the cube root twice, and square the result.

To illustrate the application of this rule for rating, take the following data:

$$L = 42 \text{ feet}$$

$$W = 8{,}400 \text{ pounds}$$

$$H = 120$$

Then

$$\sqrt[3]{120} = 4.932$$

$$\sqrt[3]{42} = 3.476$$

$$42^{\frac{1}{6}} = \sqrt{3.476} = 1.865$$

$$\sqrt[3]{8{,}400} = 20.33$$

$$\sqrt[3]{20.33} = 2.73$$

$$(2.73)^2 = 7.45$$

$$\text{Then } R = \frac{200 \times 4.932 \times 1.865}{3 \times 7.45} = 82.3.$$

With regard to the measurement of the three items involved, the following may be noted:

L results from direct measurement, in accordance with the customary rules in force.

H results from direct measurement and computation, in accordance with the rule for power.

W for small or moderate sized boats may be determined most satisfactorily by direct weighing in running condition. Where this is impracticable, the immersion fore and aft in running condition may be carefully noted and the corresponding weight determined from the displacement, which may be found either (1) by a special computation based on measurements taken from the boat when in dock, and by methods familiar to naval architects, or (2) by a special computation based on a certified draft of the lines of the boat furnished by the builder, or (3) taken direct from a certified displacement curve furnished by the builder.

GENERAL OBSERVATIONS.

In specifying the value of the numerical factors in the formula for rated engine power, two general divisions were assumed—high speed and moderate speed; or in the terms employed in the rules of the American Power Boat Association, "automobile racing boats" and "all others." By the same rules, the automobile racing boat is defined as one whose rating exceeds ten times the square root of its load water line length. Translating this into terms of speed, by the relation explained above, this means a boat whose speed by formula should exceed 2.4 times the square root of the water line length. In this form the rule is more intelligible, as we readily see what it means in the case of any given boat. Thus most of the so-called automobile or high speed boats have been from about 40 to 50 feet in length. This means then for a 40-foot boat that the expected speed will exceed 15.2, and for a 50-foot boat that it will exceed 17. These speeds are very moderate for distinctly high speed boats, and it may be asked whether the limit of rating should not be raised to about 13 times the square root of the load water line length, which would mean a speed for the 40-foot boat of about 20 knots or more, and for the 50-foot boat of about 22 knots or more.

Again, these general divisions of high speed and moderate speed boats may be separated into subdivisions in accordance with structure, and into classes with reference to rating. Thus in the rules of the American Power Boat Association the miscellaneous division is divided into two subdivisions comprising (1) cabin boats and boats with standing awnings, and (2) hunting launches and open boats. Again, each of these with the high speed division is subdivided into seven or eight classes, according to rating.

This extended subdivision has the effect of bringing into any one class only such boats as are within about 2.5 knots of each other in expected or rated speed, and under such conditions the amount of compensation to be provided by the time allowance is reduced to comparatively small limits, and may be accepted as reasonably fair, provided only that the ratings themselves are reasonably accurate.

The general basis of the rating has been discussed in detail, and by way of further comment it will be sufficient to note the following points:

(1) The accuracy of the rating depends on two chief items—the horsepower rule, and the rating formula.

(2) Of these two, the latter is presumably on the more satisfactory basis, especially having in view the subdivision of the boats into comparatively narrow classes.

(3) The chief difficulties in providing a satisfactory formula for horsepower are:

(*a*) Uncertainty and difference of opinion as to a fair basis of rating between two-cycle and four-cycle engines.

(*b*) Uncertainty and difference of opinion as to what are fair values of the revolutions or piston speed for boats of any specified group or subdivision, and also as to the proper corresponding values of the mean effective pressure.

(4) If all those who are building engines for motor boats could come together on a definite basis of agreement as to the points in (3), there would be but slight ground for dispute as to the fairness of a rule worked through on the general basis above developed.

(5) No matter what may be the rule or basis of agreement for any one year, it is probable that revision will be needed from year to year, to keep pace with the trend of development in piston

speed, in rotative speed, and in special or novel features, such as the introduction of a compressor, etc.

(6) Any rule which would fulfil ideal conditions and be beyond criticism from the engineering or scientific view point would of necessity be so cumbersome and complicated as to be quite useless for general application, and in consequence, for actual use, a rule must be employed, admittedly imperfect and approximate, and even in some cases bearing unequally on different designs, but nevertheless a rule which can be applied without prohibitive labor and which, with some attempt at agreement among those concerned as to the items in (3) above, will be reasonably satisfactory in operation.

THE USE OF ALCOHOL AS A FUEL FOR GAS ENGINES.

BY H. DIEDERICHS.

THE FUEL.

Under date of April 17th, 1906, the papers brought the news that the House of Representatives had passed the alcohol bill. By the provisions of this bill domestic alcohol of such degree of proof and such regulations as the commisioner of internal revenue may prescribe may be withdrawn without the payment of an internal revenue tax, for use not only in the arts and industries, but for fuel, light and power. The recent passage of this bill also by the Senate makes a consideration of the properties of alcohol for power purposes of great interest at the present time. Just now alcohol appears to be the only possible competitor of gasoline, kerosene or crude oil for general power work. One may even go a step further than this, and claim that finally alcohol will be *the* fuel for power generation; for while the production of coal and the crude oil products is probably limited in time, alcohol can be grown for all time in the measure that the arts and industries demand it.

The present article will consider the fuel value and the physical properties of alcohol, and the details of the alcohol engine, wherever they may be different from those of a gasoline or crude oil machine. Further, the efficiency and cost question will be briefly discussed.

Ethyl alcohol, whose chemical formula is C_2H_6O, may be made in various wavs but the commercial alcohol of to-day is the result of fermentation, generally of grape sugar, in the final stage. The raw materials are various. Thus, according to Sand* they may be divided into three classes:

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*Sand, *Zeitschrift des Vereines deutscher Ingenieure*, 1894, page 933.

1. Those containing starch,—potatoes, with 15 to 24 percent starch,
rye, with 50 to 56 percent starch,
corn, with 60 percent starch.
2. Those containing sugar,—sugar beet, with 8 to 18 percent sugar,
sugar cane, with 12 to 16 percent sugar.
3. Those containing alcohol,—wine with 9 to 16 percent alcohol.

The method of manufacture, of course, varies with the raw material, but need not be described in detail here. Theoretically, 100 pounds of grape sugar should yield 51 pounds of pure alcohol; in reality the yield is from ⅕ to ⅓ less than this amount.

A second method of producing alcohol, notably mentioned by Witz in his "Moteurs à Gaz et à Pétrole," is to start with calcium carbide as a raw material. This, by a somewhat complicated process, can be changed from CaC_2 through the stages of C_2H_2 and C_2H_4 to alcohol, C_2H_6O. Barium carbide or strontium carbide can be used in the same way. Witz states that from 1 kilogram (2.2 pounds) of calcium carbide 0.8 liter (1.69 pints) of alcohol can be obtained; this is equivalent to 0.096 United States gallons of alcohol from 1 pound of carbide. Estimating the price of carbide at 3 cents per pound, which is even now somewhat below the market price, 1 gallon of alcohol would therefore cost, in raw material alone, 31.2 cents, to say nothing of the cost of the chemical operations. The by-products in the case of the calcium carbide do not amount to much. There is consequently little likelihood that the so-called synthetic or mineral alcohol will ever seriously compete with gasoline or kerosene for power, as will be shown later.

The heating value of alcohol can not be accurately computed from its chemical composition, because nothing definite is known of the arrangement of the atoms entering the composition. We therefore have to depend upon the calorimeter. The figures determined for absolute alcohol by various experimenters are as follows:

	Higher heating value per pound	Lower heating value per pound
Thompson,	13310 B. T. U.	12036 B. T. U.
Favre & Silberman,	12913 "	11664 "

The value 11664 B. T. U. is the one most generally used. Absolute alcohol has a specific gravity of 0.7946 at 15° C (59° F), so that one gallon of pure alcohol weighs 6.625 pounds, and has a lower heating value of 77,274 B. T. U.

One pound of C_2H_6O contains 0.522 pound carbon, 0.130 pound hydrogen, and 0.348 pound oxygen.

According to this there will be required for the combustion of one pound of absolute or 100-percent alcohol

$$\frac{(0.522 \times 2.66) + (0.130 \times 8) - 0.348}{0.23} = 9 \text{ pounds of air.}$$

This is the equivalent of 111.5 cubic feet of air at 62° F, per pound of C_2H_6O. Commercial alcohol, however, is never pure, but nearly always contains a certain quantity of water, the admixture being measured according to volume percent. Thus, 90-percent alcohol means that the mixture carries 10 percent by volume of water. The heating value of such alcohol is of course correspondingly reduced from that of 100-percent alcohol according to the following table, due to Schöttler:

Absolute alcohol volume—percent	Specific gravity	Absolute Alcohol weight—percent	Lower heating value per pound B. T. U.
95	0.805	93.8	10880
90	0.815	87.7	10080
85	0.826	81.8	9360
80	0.836	76.1	8630
75	0.846	70.5	7920
70	0.856	65.0	7200

It is required by law, in countries where alcohol is now used in the industries, to so fix the fuel that it is rendered undrinkable. This process is called "denaturizing" the alcohol. The bill at present before Congress provides for the same thing. The materials used for this purpose differ in the various European countries. Some of them try to keep the process a secret, hence some of the information given in the following table* is based upon analyses.

MATERIALS USED TO DENATURIZE ETHYL ALCOHOL.

Country	Sp.Gr. of Denaturized Alcohol at 15° C	Methylene (wood alcohol) and its impurities percent	Pyridine or Pyridine Bases percent	Acetone percent	Benzol percent	Benzine percent
France	0.832	7.5	—	2.5	—	0.5
Germany						
Denat. Alcohol	0.819	1.5	0.5	0.5	—	—
Motor Alcohol	0.825	0.75	0.25	0.25	2.0	—
Austria						
Denat. Alcohol	0.835	3.75	0.5	1.25	—	—
Motor Alcohol	0.826	0.5	trace	trace	2.5	—
Russia	0.836	10.0	0.5	5.0	—	—
Italy						
Motor Alcohol	0.835	6.5	0.65	2.0	1.0	—
Switzerland	0.837	5.0	0.32	2.2	—	—

It will be noted from the table that the material most used for denaturizing ethyl alcohol is wood alcohol. The heating value of the fuel is by the addition of the denaturizing liquid changed but little in most cases.

Benzol, C_6H_6, besides being used for denaturizing, is sometimes used in larger quantities than indicated in the above table

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***Zeitschrift des Vereines deutscher Ingenieure*, June, 1905.

for the purpose of increasing the heating value of the fuel mixture per pound. Benzol has a specific gravity of 0.866 and a heating value of 17190 B. T. U. per pound. A mixture of x percent by weight of absolute alcohol with y percent of benzol will therefore have a heating value of

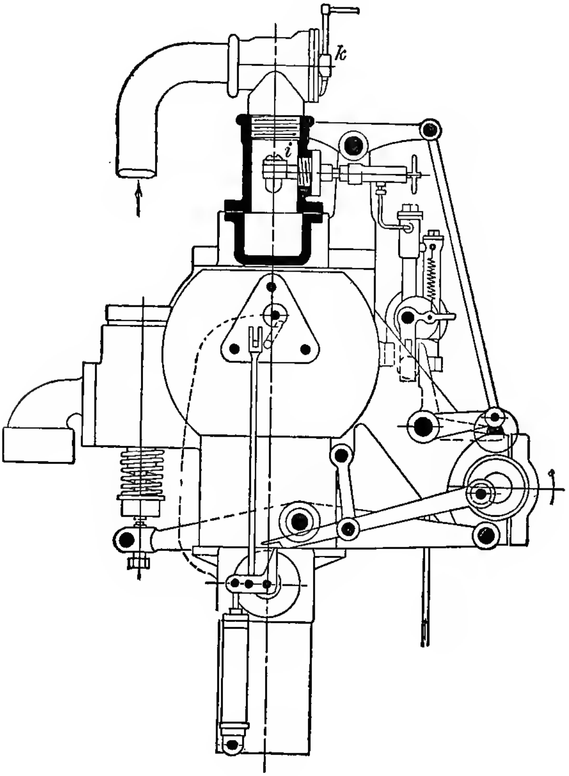

FIG. 1.

$$[11664\,x + 17190\,y] \text{ B. T. U. per lb}$$

If the alcohol is not absolute, its proper heating value should be substituted from the table above given. In this way from 10 to 40 percent of benzol is sometimes employed, thus raising the heating value of the fuel, and at the same time decreasing the specific heat cost, i. e., the cost per heat unit.

There is a second reason why benzol is employed. Under certain circumstances there will be formed acetic acid in the products of combustion of alcohol. This causes rusting of the engine parts. On examination it will be found that this is due to a combustion with insufficient air supply, and the surest way to prevent rusting therefore is to use a good excess of air. and to have a perfect mixture. Under such conditions there will be no danger of corrosion. It is also found that a good addition of benzol acts as an additional safe-guard. It should not be forgotten in this connection, however, that the great advantage possessed by alcohol in its odorless exhaust is sacrificed to some extent by the use of benzol.

THE ENGINE.

Taking up next the mechanical details of the alcohol engine, we find that they do not differ materially from those of the ordinary gasoline engine. As a matter of fact, any gas or gasoline engine can be run on alcohol, if only a means be provided to form the fuel mixture. The first trials with alcohol were made on liquid fuel engines so provided. It was soon discovered, however, that the efficiency of operation of alcohol engines could be materially increased, if the compression were increased above that possible for gasoline. Hence this is the main point of difference between gasoline and alcohol engines. The other point is the one above mentioned, i. e., that a different vaporizer or carburetor is required.

There has naturally been very little work done on alcohol engines on this side of the water. In Europe, however, especially in Germany and France, there are to-day many alcohol engines in operation, used mostly in agricultural industries. For this purpose the other advantages possessed by alcohol overbalance the somewhat greater operating costs. One such advantage is the greater safety of alcohol as compared with gasoline, which makes the packing and shipping so much easier, and the conditions imposed by insurance companies much less strict and hence less irksome, to say nothing of the lower cost of insurance. Again, the production of alcohol is not confined to certain localities, as is that of a product like crude oil, gasoline or kerosene. It may be grown and made almost anywhere, and hence the freight charges to the consumer will in most cases be comparatively smaller than for the crude oil products.

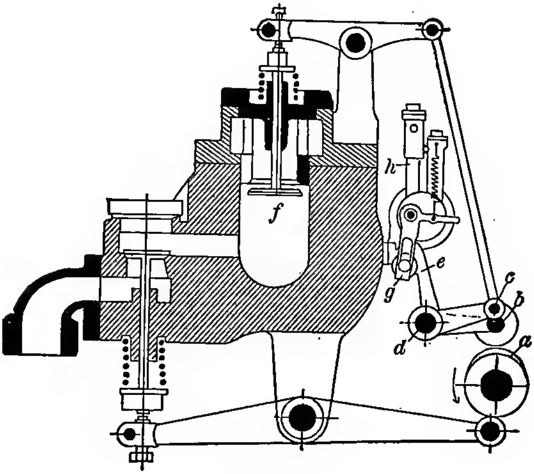

FIG. 2.

It is therefore to Germany that we have to look for information regarding alcohol engines. The following material is taken mainly from the work of E. Meyer* and of R. Schöttler**, and from the discussions of Güldner†, Diesel†† and others, published in the *Zeitschrift des Vereines deutscher Ingenieure.* To all these the writer desires to render his acknowledgment.

Regarding the formation of the fuel mixture with alcohol, it is found that it is less volatile than gasoline, but easier to handle than kerosene. In nearly all of the vaporizing devices for alcohol now on the market, the agency of heat, usually the exhaust heat of the waste gases, is used to aid in the formation of the mixture. This scheme has the drawback that no heat is available at the start when the engine is cold, and it is next to impossible to start a cold engine on alcohol. To avoid an open flame for the purpose of heating the vaporizer at the start, which is both dangerous and cumbersome, the engines in most cases are started with gasoline, and when, after a few strokes, enough heat is available, the change is usually made by throwing over a single lever. In tests of ten different engines made by Meyer, it was shown that this change to alcohol could be made in the slowest case in 6 minutes and 40 seconds, the time of the fastest being 55 seconds.

Based on the manner of heating the vaporizer, we can distinguish the following classes:

1. Those in which no heat is employed.
2. Those in which the air is preheated.
3. Those in which the mixture is heated and superheated.

Of the first type is the Deutz, Figs. 1 and 2. When the engine is regulated by the throttling method, and not by the hit and miss system, it has been found that no preheating of air or fuel mixture is required. The reason for this is undoubtedly

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*E. Meyer, *Zeitschrift d. V. d. I.*, 1903, pages 513, 600, 632, 669.
**R. Schöttler, " " " " " 1902, pages 1157, 1273.
†H. Güldner, " " " " " 1902, page 623.
††R. Diesel, " " " " " 1903, page 1366.

that in a hit and miss engine, under less than normal load, a succession of misses cools the cylinder down so far as to throw down some of the alcohol vapor on the next explosion, unless it is superheated. The Deutz engine is governed by throttling.

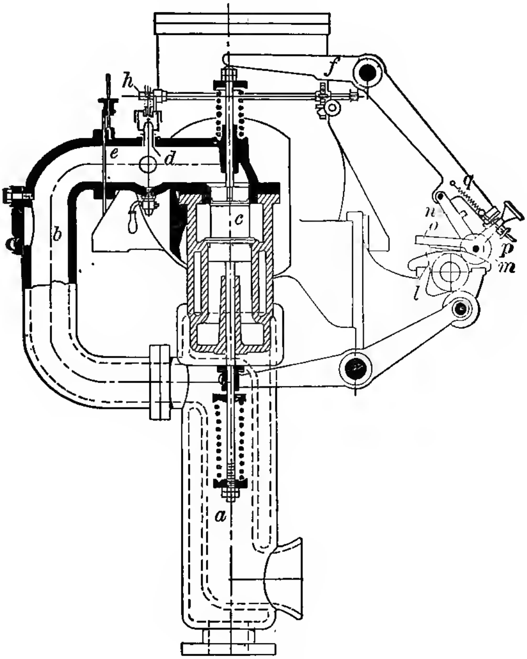


FIG. 3.

The inlet valve, *f*, is actuated through the levers shown, by the cam, *a*, which is of taper form and under the control of the governor. Upon the position of *a* depends the length of time the valve, *f*, is open. Through the bell crank, *c d e*, the cam also acts upon the plunger of the fuel pump, *h*, operating in such a way as to cause suction during the first part of the cam movement, and pumping of the liquid during the second. Thus the fuel is injected during the second half of the suction stroke only, insuring a rich mixture around the igniter. The alcohol is forced through the sprayer or atomizer, *i*, Fig. 1, into the current of air which enters through the valve, *k*. Thus no preheating whatever is done, but the atomizing is thorough; and the ports into the cylinder are as direct and short as possible, hence no vapor is thrown down.

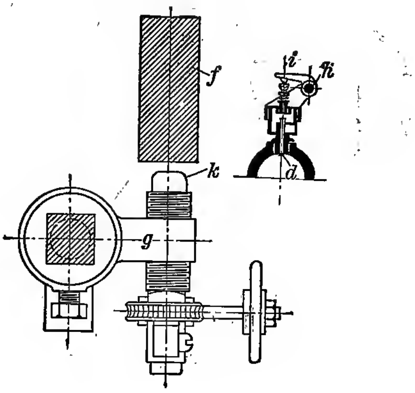


FIG. 4. FIG. 5.

The Altman vaporizer, Fig. 3, is of the second class. The air pipe *a—b* is surrounded at its lower end by the exhaust pipe; the air is thus preheated by the exhaust gases. A regulating valve for the air is placed at *e*. This, when drawn upward, decreases the amount of air passing, but always makes the air current strike through the upper part of the pipe, in this manner directing it always against the fuel nozzle, *d*. The inlet valve, *c*, is operated by the lever, *f*, actuated by the cam, *l*, through the pendulum hit and miss governor *o m p*. This valve lever, *f*, at the same time opens the fuel valve, *d*, through the reach rod shown and the finger, *h i*, Fig. 5. How this is done is shown in Fig. 4. The lever, *f*, on being depressed, forces down the point of the screw, *k*, thereby turning the reach rod about its axis, which depresses the point, *i*, Fig. 5, opening the valve *d*. The amount of opening depends upon the position of the screw, *k*, and this can be very finely adjusted by the worm and wheel arrangement shown. In this vaporizer the fuel supply is atomized partly by the current of air, and is afterwards vaporized by the heat of the preheated air.

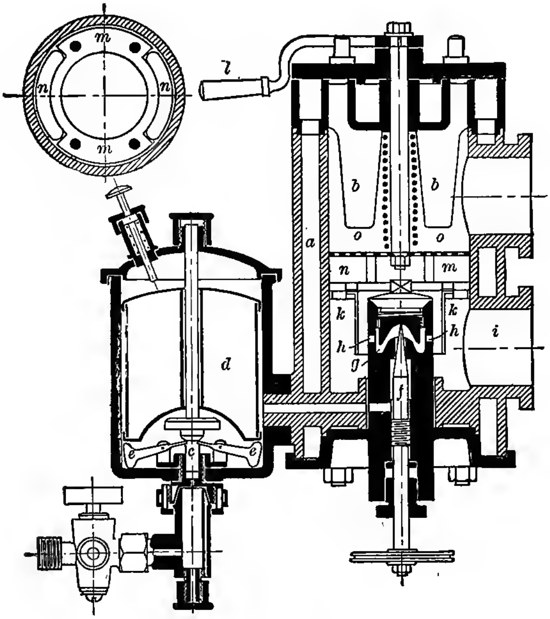


FIG. 6.

The following three vaporizers are of the third class. Fig. 6 shows the Swiderski-Longuemarre. Here also the exhaust gases are used for heating. They pass through the annular chamber, *a*, and their action is aided by the radiating webs *b—b*.

The float, *d*, maintains a constant level in the supply chamber. From this chamber the flow of alcohol is regulated by the needle valve, *f*. The liquid flows into the space *g*, and overflows through a number of small openings, *h-h*. Air entering through *i* is made to pass partly outside, partly inside the concentric spaces created by the sleeve, *k*. The amount of air passing outside is regulated by the openings, *n—n*, which are controlled by the lever, *l*. The air currents passing upward carry along with them some of the liquid, the mixture being heated by the exhaust gases in *a*. The perforated plate, *o*, tends to aid in forming a uniform mixture.

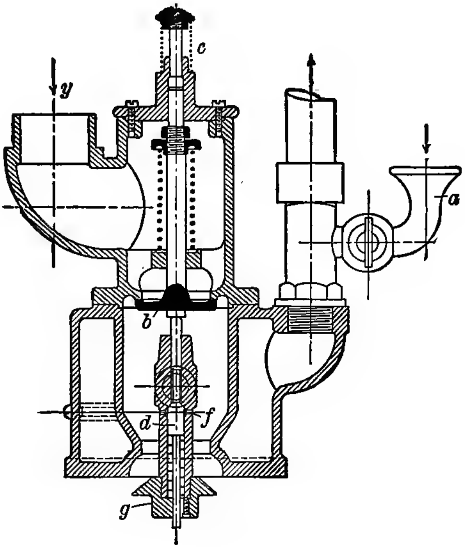


FIG. 7.

The vaporizer of the Dresdener Gasmotorenfabrik is shown in Figs. 7 and 8. In this case the warm cooling water of the engine is used for heating. It enters the water space at *x*. On very cold days the vaporization may be assisted at the start by pouring some hot water into the funnel, *a*. Air enters at *y*. The inlet valve, *b*, is automatic. It may be pushed down at will at the start by pressing down on the projecting stem, *c*. The downward movement of the inlet valve opens the fuel valve, *d*, to which alcohol is furnished through the needle valve, *e*, Fig. 8. Through a number of fine openings the fuel flows into the current of air and is carried along with it, the thorough mixing being assisted by the current striking the cone, *g*. As will be seen from the drawing, the heating of the charge can not be very high. In the first place only the comparatively cool jacket water of the engine is used, and secondly the mixture itself is not in the heated chamber for any length of time.

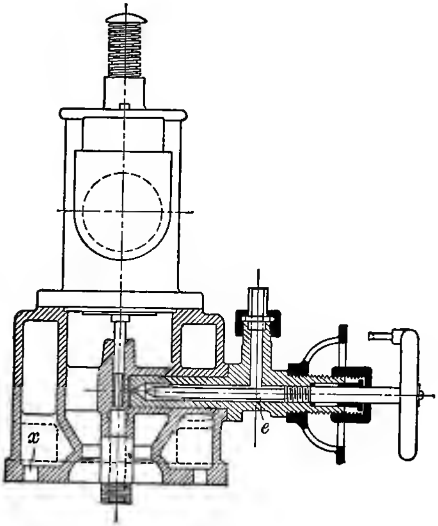


FIG. 8.

In contradistinction to the Dresden vaporizer, the Dürr, Fig.

9, produces a highly heated mixture. Air enters at *x* and its amount is regulated by the throttle valve, *a*. The inlet valve, *b*, is automatic. Alcohol is supplied through the needle valve, *c*, as shown, so that when *b* is closed no flow of alcohol takes place. The current of air charged with alcohol particles passes down through *d*, up the annular space, *e*, and out at *y* to the cylinder. The exhaust gases enter at *z*, and by means of baffle plates are made to take the course shown by the arrows, through the space *f*. Further, the space *e* is filled with a large number of metal spirals, which connect the outside wall of *e* with its inside wall, thus furnishing a large heated surface to the passage of the charge, and facilitating the transfer of heat from the space *f* to the space *d*. Every possible way is therefore made use of to apply the heat of the exhaust gases, and this vaporizer therefore furnishes a mixture more highly superheated than that of the others.

Finally, Fig. 10 shows what may be called a double float carburetor, which is the form that alcohol vaporizers are likely to take. This is used on the Marienfelde machines. Assume that the chamber *a* is used for gasoline, *b* for alcohol. The needle supply valves can be held closed by the springs *c* and *d*, as shown.

On starting with gasoline, the chamber *a* is used. Spring *c* is pushed aside so that fuel can enter, being kept at constant level by the float. The valve, *g*, is so set that the path is open for the air from *h* past the gasoline nozzle, *e*, through *g* into the cylinder. At every suction stroke the inrushing air is then charged with gasoline issuing in a small jet from *e*. If it is desired to change to alcohol, spring *c* is pushed into place, spring *d* is pushed aside, and valve *g* is thrown over into the position shown in Fig. 10, all the work of a moment. The air supply to this vaporizer is preheated.

It is quite evident from an examination of the vaporizer above described that the final temperature of the mixture is different in the different devices. Upon this temperature, however, depends in a great measure the only other point of difference between gasoline and alcohol engines, i. e., the amount of compression. All other things being the same, that fuel mixture entering the cylinder at the highest temperature will soonest give rise to preignition, or at least to pounding, under an increase in compression. High temperature of charge also affects engine capacity unfavorably. It therefore becomes important to determine approximately the *lowest* practical temperature of vaporization, and the heat necessary.

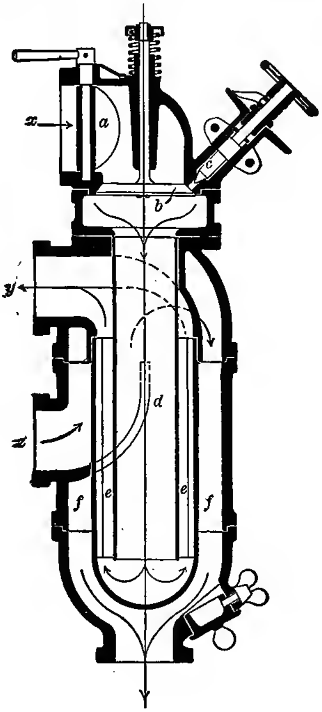


FIG. 9.

Of course the amount of heat required depends upon the amount of alcohol (and its purity) per pound or cubic foot of air. Assuming that 90-volume-percent alcohol is used, the theoretical amount of air required for perfect combustion is 7.8 pounds. Assuming that an excess of 50 percent of air is used, which is a desirable allowance, 1 pound of 90-percent alcohol would require in round numbers 11.7 pounds of air. With the air temperature at 60° F, and the atmospheric pressure 14.7 pounds per square inch, this amounts to 0.0065 pound of 90-percent alcohol per cubic foot of dry air.

90-percent (volume) alcohol is equivalent to 87.7 (weight)-percent, so that 1 pound of air will carry, according to the above assumed ratio of mixture,

$$0.877 \times \frac{1}{11.7} = 0.075 \text{ pound of absolute alcohol,}$$

and $$0.123 \times \frac{1}{11.7} = 0.010 \text{ pound of water.}$$

To compute the air temperature required so that it may take up the above quantities of alcohol and water vapor, we must know the relation between the temperature and the degree of saturation. Meyer in his computations used the data contained in the

Temperature Degs. F.	Vapor Tension Inches Mercury		1 pound of air contains in saturated condition, in pounds			
			At 28.95 inches Hg. Press.		At 26.05 inches Hg. Press.	
	Alcohol Vapor	Water Vapor	Alcohol Vapor	Water Vapor	Alcohol Vapor	Water Vapor
50	0.950	0.359	0.055	0.008	0.061	0.009
59	1.283	0.500	0.075	0.011	0.084	0.013
68	1.733	0.687	0.104	0.016	0.117	0.018
77	2.325	0.925	0.144	0.022	0.162	0.025
86	3.090	1.240	0.200	0.031	0.227	0.036
104	5.270	2.162	0.390	0.063	0.450	0.072
122	8.660	3.620	0.827	0.135	1.002	0.164

Physikalisch-Chemische Tabellen of Landoldt & Börnstein. For our purpose the figures of the table have been transposed into English units.

In the ordinary case the air drawn into the vaporizer is not dry, but contains a certain quantity of water. Assume that the air is at a temperature of 59° and just saturated. At a pressure of 26.05 inches of mercury this would correspond to 0.013 pound of water per pound of air in its initial condition. Now in the case of the average mixture above computed, the temperature of vaporization must be high enough to vaporize an additional 0.010 pound of water, making the total 0.023 pound that the air must contain per pound. It is seen from the table that a temperature of 77° is quite sufficient to do this. It is also seen that at this temperature the air may take up 0.162 pound of absolute alcohol, while the quantity in the above mixture is only 0.075 pound per pound of mixture. At a temperature of 77°

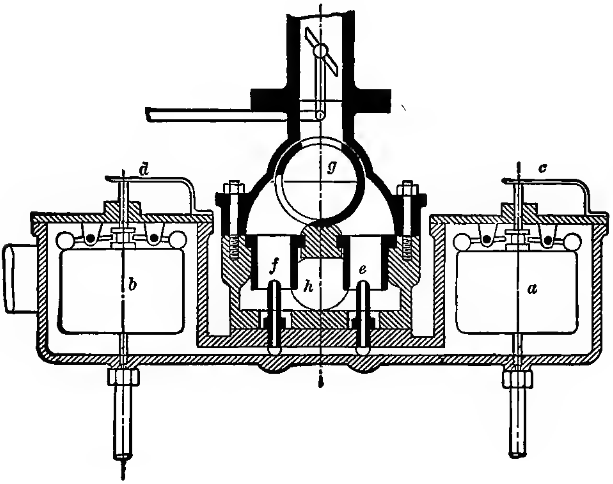


FIG. 10.

the mixture ready for the cylinder may therefore contain the alcohol vapor in a state of some superheat. If therefore the temperature of the walls with which the mixture comes in contact is not less than 77°, no fear of condensation of alcohol vapor need be entertained. In this connection a statement in the *Engineering Record* is of interest. It is there claimed that the consumption of alcohol with the jacket water leaving at 60° F is 100 percent higher than with jacket water leaving near 212°; i. e., with cooling by vaporization. In the light of the above facts, some such increase in the consumption is quite possible.

In order to convert the liquid alcohol into vapor, a certain quantity of heat is required. According to Regnault, this amount is, for the various temperatures given, and computed above 32° F, as follows:

At 32° F	425.7	B.	T.	U.	per pound
68° F	453.6	"	"	"	
122° F	475.2	"	"	"	
212° F	481.1	"	"	"	

The specific heat of liquid alcohol is close to 0.6, so that in order to convert the quantity of 90 volume-percent alcohol contained in the assumed mixture, to alcohol vapor at 77° F, would require approximately, assuming the liquid alcohol at 60° F,

$$0.075 \times [458 - (28 \times 0.6)] + [0.010 \times 1100] = 44.1 \text{ B. T. U.}$$

where 1100 B. T. U. is assumed as the heat of vaporization of water under the existing conditions.

Now the heating value of 90 volume-percent alcohol has been shown to be 10080 B. T. U. per pound, so that the heating value on one pound of our assumed mixture will be $0.075 \times 10080 = 756$ B. T. U. The heat of vaporization required is therefore $\frac{44.1}{756} = 5.8$ percent of the heating value of the fuel. It can be shown that the amount of heat is easily obtainable from the exhaust gases. It can also be shown that the problem may be solved by preheating the air only, for, assuming that the specific heat of air at constant pressure is 0.238, we would have to preheat the air for the assumed mixture to $\frac{44.1}{.238} + 77 = 262^\circ$ F, which is easily possible.

If, on the other hand, not the air but the mixture is heated, then the walls need to have a temperature only sufficiently higher than 77° to transfer the required amount of heat for vaporization to the mixture in the time available. To furnish more heat than this is harmful, if anything, for it affects unfavorably both the possible degree of compression and the capacity of the machine. The cooler the mixture after formation and vaporization, the better.

This point was strikingly brought out in the tests made by E. Meyer in 1902. As above explained, the Deutz vaporizer uses no heat either for the air or the mixture. The walls of the chamber near the atomizer felt cold to the touch, and during the tests were covered with water vapor. This shows conclusively that the alcohol in the mixture could not have been completely vaporized. The ports from the atomizer to the cylinder are in the case of the Deutz engine very direct and short, so that probably no serious separation of liquid occurs. Once in the cylinder the vaporization is quickly effected, for the cylinder walls are hot, the method of cooling used being that by vaporization. In any case, however, the final mixture is comparatively cool, and the degree of possible compression correspondingly high, the ratio of compression during the tests being 8.9.

The Dürr vaporizer, on the other hand, gives the most highly diffused and highly heated mixture. A highly diffused, i. e., a perfect mixture, of course affects the alcohol consumption favorably, and for that reason the consumption of the Dürr engine per horsepower-hour was not much greater than that of the Deutz. But the high temperature of the mixture compelled the use of a lower degree of compression, the ratio used being 5.68, and even at this point the explosions in the Dürr engines were sharper than those in the Deutz. If the Dürr machine had been able to use the same degree of compression as the Deutz, Meyer figures that its fuel consumption would have been lower than that of the latter.

It may be asked why a higher compression should show a better fuel consumption per horsepower-hour, i. e., a better thermal efficiency. It can be shown on theoretical grounds that the thermal efficiency of an Otto cycle can be expressed by

$$E_t = 1 - \frac{1}{r^{n-1}}$$

$$\text{where } r = \text{ratio of compression} = \text{ratio of } \frac{\text{total cylinder volume}}{\text{clearance volume}}$$

$$n = \frac{C_p}{C_v} = \text{ratio } \frac{\text{specific heat of charge at constant pressure}}{\text{specific heat of charge at constant volume}}$$

Evidently E_t is the greater, the greater the value of r, i. e., the smaller the clearance volume, and hence the higher the compression. And it is found that this theoretical formula is borne out in practice.

The best results so far attained in practice have been with a compression pressure of about 200 pounds. The average compression pressure for good results may be taken at 180 pounds. The corresponding maximum explosion pressure is about 450 pounds.

With the exception of the carburetor and the compression, the design of the alcohol motor does not differ from that of a gasoline machine, as is shown by Fig. 11, which represents a two cylinder launch engine built by Marienfelde. Alcohol is contained in the vessel, *a*, which is filled through the strainer, *b*. The tank, *a*, is kept under a certain definite pressure by means of the exhaust gases, which forces the alcohol into the left hand float chamber of the vaporizer, *c*. Part of the exhaust gases pass through the strainer, *f*, the check valve, *h*, and the pipe, *e*, to the fuel tank. *g* is a safety valve, so that by means of this and the check valve, *h*, a constant pressure is maintained on the liquid in the tank. The inlet valve, *i*, is automatic, while exhaust valve, *k*, is mechanically operated. The fresh air passes through a heater surrounding the exhaust pipe and is thus preheated on

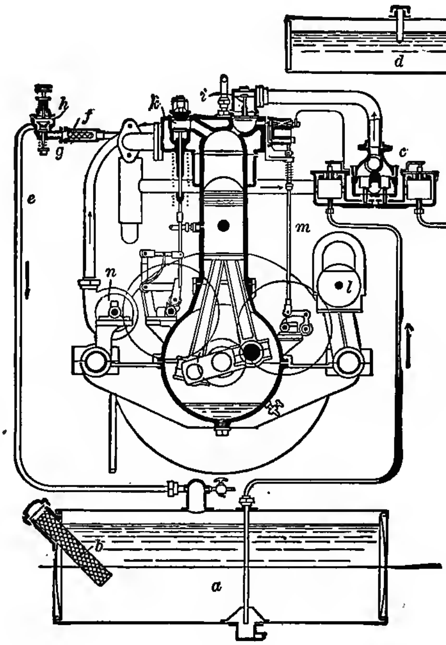


FIG. 11.

its way to the vaporizer. The volume of these preheaters is made from 0.12 to 0.15 of the stroke volume. Ignition is produced by means of the electro-magnetic apparatus *l*, *m* being the make and break gear. Regulation is effected by the hit and miss system. *n* is a small rotary pump, driven as shown, to furnish circulating water for the jacket. The supply of gasoline required to start the machine is kept in a tank *d*, at higher level, so that the fuel is supplied to the right hand float chamber by gravity. The operation of the vaporizer was explained under Fig. 10.

The following table of dimensions of Marienfelde engines gives some idea of the size of the machines:

Maximum Brake Horsepower	R. P. M.	Cylinder Diameter Inches	Stroke Inches
8.0	220	6.70	11.80
13.2	220	7.90	14.20
21.0	202	9.85	15.75
24.5	200	11.00	15.75
30.0	200	13.80	15.75

EFFICIENCY.

There remains to be considered the efficiency of the alcohol engine and the cost of operation.

Again, next to nothing has been published in this country regarding these points, and we are compelled to turn to other sources. The most extensive testing work has been done by E. Meyer in 1902, for the German Agricultural Society. While the results there obtained were uniformly good, they have been bettered since then, mainly through a further increase in compression. The cost of operation is of course intimately related to the efficiency, and the two will therefore be considered together.

Regarding the specific heat costs of gasoline, kerosene and alcohol, the price of gasoline may be assumed at an average of 15 cents per gallon, that of kerosene at 13 cents. The price of denaturized alcohol is of course still undetermined as far as this country is concerned. In Germany 90 volume-percent alcohol was sold at 15 pfennige per kilogram in 1902. This is equivalent to about 11.5 cents per gallon. In 1905, however, the price of alcohol was raised to 25 marks per 100 kilograms, i, e., to 19 cents per gallon, by the alcohol trust. Regarding the United States, the only reference the writer has been able to find is contained in the *Iron Age,* March 15, 1905. At a hearing of the Ways and Means Committee, Mr. Kline, representing the Philadelphia Trades League, brought out the following facts, referring to a distillery located in Illinois:

"The cost of production has fallen as low as 5.2 cents per proof gallon, equal to 9.77 cents per wine gallon testing 94 percent, or 9.36 cents per wine gallon testing 90 percent.

"The average cost per proof gallon during the entire period of 10 years was 10.78 cents, equal to 20.26 cents per wine gallon, 94 percent, or 19.4 cents per wine gallon, testing 90 percent.

"The average cost of corn during the entire period of ten years covered by these records was 42.36 cents per bushel, and the average yield from each bushel was 4.76 proof gallons."

It was further mentioned that alcohol, to be used for beverage purposes, or for use in manufacturing perfumery, flavoring extracts, etc., can be made from merchantable grain only. For the production of denaturized alcohol, however, inferior materials could be employed, thus cheapening production.

In view of the above facts it seems improbable that alcohol testing 90 percent, from merchantable raw material, will ever

Fuel	**Heating Value per Pound B. T. U.**	**Cost per**		**Specific Gravity**	**Cost of 10000 B. T. U. Cents**
		Gallon Cents	**Pound Cents**		
Gasoline	19000	15.0	2.57	0.710	1.35
Kerosene	18500	13.0	1.88	0.800	1.02
Alcohol, 90 percent	10080	15.0	2.21	0.815	2.19

be sold for much less than 20 cents a gallon. But assuming that the use of inferior raw materials may eventually bring its cost down to 15 cents per gallon, the specific heat costs of the liquid fuels mentioned would be as per table:

It is seen at once that alcohol is saddled at the outset with a very serious handicap in the way of greater specific heat cost, as compared with either gasoline or kerosene. To be on a par, therefore, regarding cost of operation, the thermal efficiency of the alcohol engine would have to be $\frac{2.19}{1.35} = 1.62$ times greater than that of gasoline, and $\frac{2.19}{1.02} = 2.15$ times greater than that of kerosene, everything else in the way of engine losses being the same. It remains to be seen how far this has been realized in practice.

In 1903 Diesel found the best figures for the thermal brake efficiencies of gasoline and kerosene engines so far attained to be 20.5 percent for gasoline and 17.6 percent for kerosene. This corresponds to a consumption of 0.654 pound of gasoline and 0.727 pound of kerosene per brake horsepower-hour. Banki, with his water injection principle, had reached as high as 27.5 percent thermal brake efficiency, equivalent to 0.487 pound of gasoline per brake horsepower-hour, but this is a special case. Allowing for some further improvement in gasoline and kerosene engines since 1903, we will assume the best thermal brake efficiency for gasoline 23 percent, and for kerosene 18 percent.

The best figure obtained by Meyer in the competitive tests of 10 alcohol engines in 1902 was 365 grams of 90 percent alcohol per brake horsepower-hour for the Deutz engine. This corresponds to 0.803 pound of alcohol per brake horsepower-hour and a thermal efficiency of 31.7 percent. The end compression in this case was about 190 pounds, the explosion pressures exceeded 450 pounds per square inch. It is possible to increase this high efficiency by the use of still higher degrees of compression, but it is questionable whether the use of such high compressions is advisable in average practice. The maintenance and care of the machine become more and more difficult, and it becomes very sensitive to improper setting of the fuel supply valve, pounding and knocking and otherwise unsteady running occurring very easily.

The use of benzol-alcohol mixtures has already been mentioned. The cost of benzol will probably not be very far different from that of denaturized alcohol, but on account of its greater heating value, its specific heat cost is less. The use of a 15-percent benzol-85-percent alcohol mixture has shown in Meyer's tests about the same thermal efficiency as that of alcohol alone. Hence the cost of operation with these benzol mixtures may be slightly less than that for alcohol. In spite of this fact, the use of much benzol is not advisable, because it fouls the engine after a while, making cleaning necessary from time to time.

The above economy and cost figures are collaborated in the following table:

Fuel	Cost for 10000 B T U. Cents	Best Consumption of Fuel per B. H. P. hr. Pound	Best Thermal Brake Efficiency Percent	B. T. U. per B. H. P. hr.	Fuel Cost Per B. H. P. hour Cents
Gasoline	1.35	0.580	23.0	11000	1.485
Kerosene	1.02	0.725	18.0	14140	1.442
Alcohol, 90 percent	2.19	0.803	31.7	8030	1.758

It appears therefore that at the present time, with 90-percent alcohol at 15 cents per gallon, the operation with alcohol would cost about 19 percent more than with gasoline, and about 22 percent more than with kerosene, the prices for the latter being as assumed above. It is to be hoped that this margin can be overcome, either by perfecting the machine, or by decreasing the cost of the fuel. On the basis of the above computations, 90-percent alcohol, for instance, would have to cost 12 cents a gallon, to be on a par with gasoline. The advantage of gasoline with regard to fuel cost, however, is even now not so great but that it is largely overbalanced by the already mentioned advantages of the alcohol machine, and that is the real reason why the latter has found such extended application in some European countries, in spite of its slightly greater operating cost.

THE USE OF KEROSENE OIL IN ENGINES BUILT FOR GASOLINE.

BY H. B. MAXWELL.

The constantly increasing demand for gasoline, owing to new fields for its use being rapidly developed, has caused a steady increase in price, which makes the use of the heavier and cheaper liquid hydrocarbon fuels a matter of such importance that it has for some time past attracted the attention of engineers engaged in designing internal combustion engines. There are a number of commercial engines on the market for stationary, and a few for marine, use that are regularly built to use kerosene, but in nearly all of them the designers and inventors, as is usually the case, have used a complicated mechanism to reach the desired end.

To digress a little from the subject in hand, attention may be called to the fact that gas naphtha, running from 58 to 62 degrees Beaumé, can be used successfully in any well designed four-cycle engine, and in two-cycle engines after they have been heated up by running a short time on gasoline. A few users of gasoline engines are aware of this fact, and where so situated as to obtain it use it exclusively, and as it costs only six or seven cents per gallon, the saving is quite an item.

To use gas naphtha successfully, note must be taken of the fact that, owing to its being heavier than gasoline, it takes more air to furnish the proper amount of oxygen for complete combustion. The vaporizer or carbureter should therefore be adjusted for the heavier fuel by closing the needle valve until a properly combustible mixture is found.

With any fuel, the cooling water in the cylinder jacket should be so restricted that it leaves the jacket at a temperature of from

180 to 200 degrees Fahrenheit; with air or oil cooling, higher temperatures are desirable; in fact, with any internal combustion motor using any kind of fuel the hotter it can be run without causing preignition, or destroying the lubricant, the greater the efficiency will be. It will surprise the average user of a gas or gasoline engine to make a few tests of fuel consumption with varying temperatures of the cooling water at the outlet, as it will be found that when the water circulation is so rapid as to keep the engine cold, an appreciably greater quantity of fuel will be used than will be the case where the water is raised nearly to the boiling point before leaving the jacket.

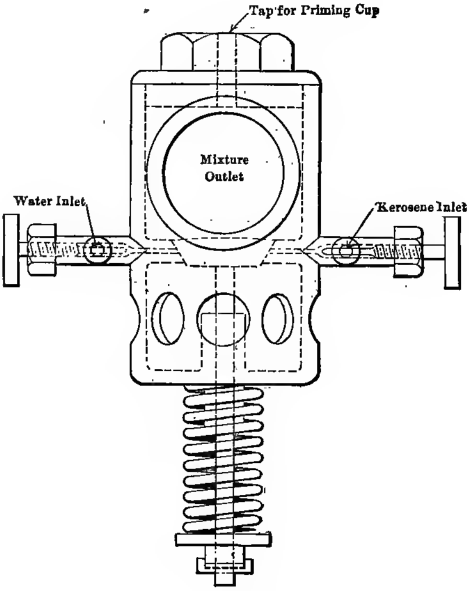


Fig. 1

Kerosene can be used in many engines after being warmed up on gasoline, but not economically unless some device is added to insure perfect combustion of the fuel or to aid in the better vaporization of the fuel before it reaches the combustion chamber. It has been found that by using a common mixing valve of the type shown in Figs. 1 and 2, kerosene can be used successfully.

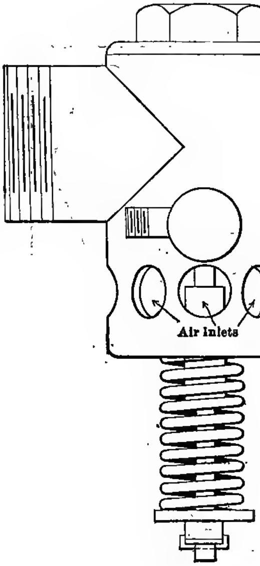
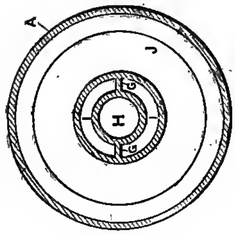


Fig. 2

Referring to Fig. 1, it will be noticed that the nut forming the cap to the body of the valve is tapped for a priming cup. This is to be filled with gasoline, and the engine started on this. As soon as the engine is heated up a little, open the needle valve controlling the kerosene inlet. After doing this a blue smoke will



SECTION AT E-F
FIG. 5

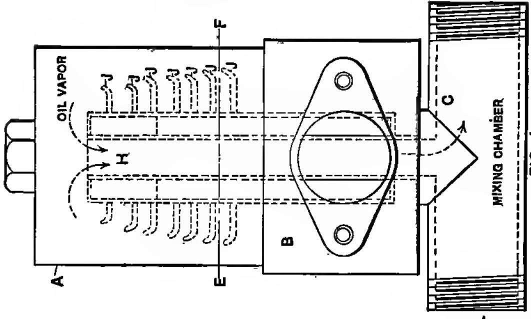


FIG. 4

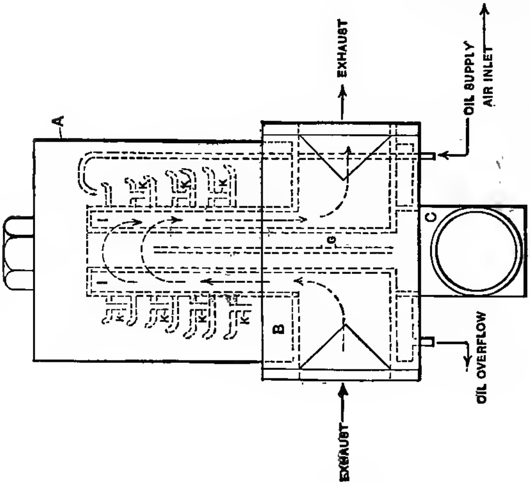


FIG. 3

KEROSENE OIL VAPORIZER

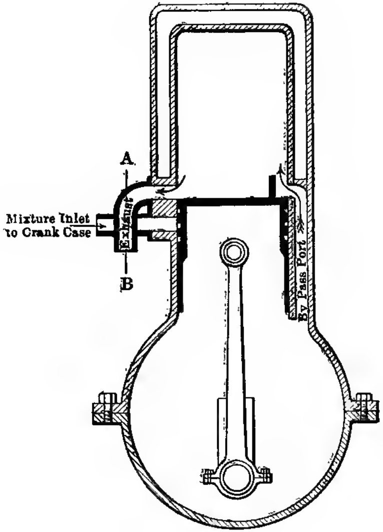


Fig. 6

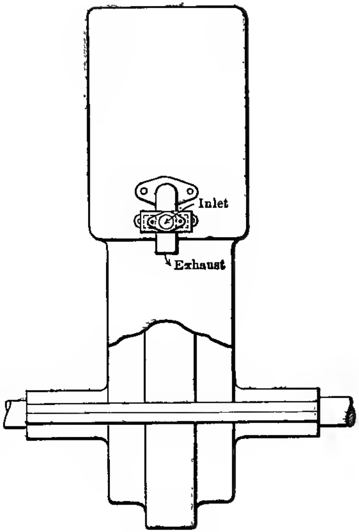
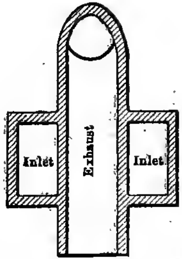


Fig. 7



Enlarged Section at A.B.
Fig. 8

be noticed at the exhaust pipe. Then turn on the valve controlling the water supply, a little at a time, until this smoke clears away, being sure that lubricating ~~oil is not~~ being used in excess. This will work on most four-cycle engines using high compression.

Figs. 3, 4 and 5 show an exhaust heated vaporizer that can be used with any engine. It consists of a body *B* and *C*, cast integral with the pipes and oil pans, ~~as~~ shown in the dotted lines, Figs. 3 and 4, and section, Fig. 5. The cap *A* screws into the body *B*, and can be readily removed to clean the pans of any tar or coke deposited from the fuel used. The oil supply may be operated by a variable stroke pump controlled by a governor, or the engine can be controlled by throttling the mixture between the vaporizer and the intake valve. ~~There must be~~ an air regulator attached to the mixture chamber *C* at the end opposite from the end used to convey the mixture to the engine.

The exhaust enters the T-shaped pipe *I I* and impinges against the pipe *H* and the guides *G G*, giving the exhaust gases the course shown by dotted arrows in Fig. 3. This imparts part of the heat of the exhaust gases to the walls of the pipe *I I* and the pans *J J*. It will be noticed that the overflow pipes *K K* from each pan to the one next below it bring the fuel not vaporized by the first hot surface into contact with other hot pans, to complete the vaporization. Any overflow is taken care of by the outlet at lower left hand side of Fig. 3. The oil, gas or vapor flows down pipe *H* to the chamber *C*, where it is mixed with the proper amount of air to furnish the correct mixture.

Figs. 6, 7 and 8 show a device designed by the writer, and *not* patented. Referring to Fig. 6, it will be noticed that the exhaust and intake pipes are cast integral. The inlet from carbureter at the left opens directly against the hot walls of the exhaust pipe, and as shown in Fig. 8, divides and passes around the exhaust pipe and enters the port to the crank case.

This works so well that it is now being applied to a two-cycle air cooled engine, with every confidence that it will solve the problem for a cheap and reliable motor. Of course, to start a two-cycle engine with this device, it must be primed with gasoline, the priming cup being located on top of the cylinder; or the combination exhaust and inlet pipe could be heated with a torch.